Effect of a Low Lignin Hull, High Oil Groat Oat on Beef Cattle Growth, Carcass Quality and Nutrient Utilization

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ABSTRACT

A series of experiments were conducted to investigate the nutritional value of a new oat variety developed by the Crop Development Centre at the University of Saskatchewan. Trials 1 and 2 evaluated performance of steers fed a low lignin hull, high oil groat (LLH-HOG) oat as a replacement for barley or corn. In trial 1, 400 steers were fed one of two diets with barley or the LLH-HOG oat at 37.8% of the diet DM. Dry matter intake was lower (P=0.02) and gain to feed improved (P<0.01) for steers fed the oat-based diet. In trial 2, 240 steers were finished diets with barley, corn or the LLH-HOG oat at 88.2% of the finishing diet (DM). During finishing, steers on the oat diet had lower (P<0.01) ADG, body and carcass (P<0.01) weights than barley or corn-fed cattle reflecting lower (P<0.01) DMI.

In trial 3, 20 steers were fed one of seven diets consisting of barley silage and 0, 28, 56, or 84% LLH-HOG oat or barley grain (DM basis) to compare nutrient digestibility. Apparent DM, OM, ADF and NDF digestibility coefficients were lower (P<0.05) for LLH-HOG oat-based diets compared to barley-based diets. Apparent CP and EE digestibility coefficients were higher (P<0.05) for the LLH-HOG oat diets.

Trial 4 was conducted to assess ruminal fermentation differences between LLH-HOG oat- or barley-based finishing diets using four rumen cannulated steers. No diet effects (P>0.05) were observed for total ruminal VFA concentration or molar proportions of individual VFA however mean ruminal pH was lower (P=0.01) for steers fed the LLH-HOG oat-finishing diet. Further, the extent of pH decline in oat-fed cattle was greater (P<0.01) than for barley-fed cattle.

The results indicate that the energy value of the LLH-HOG oat is equivalent or superior to that of barley for growing cattle. However, further research is required to identify factors limiting feed intake of cattle fed this new oat type in finishing diets.

Key words: Low lignin hull, high-oil groat oat, barley, corn, cattle performance, digestibility, carcass traits, fatty acids

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DEDICATION

I dedicate this thesis to my wife Jacquie, our children Kaitlin and Ryan and the rest of my family who made changes to their daily lives and routines so that I could pursue this academic endeavour.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADF	Acid Detergent Fibre
ADG	Average Daily Gain
ADL	Acid Detergent Lignin
BW	Body Weight
Ca	Calcium
ºC	Degrees Celsius
CCK	Cholecystokinin
CLA	Conjugated Linoleic Acid
CP	Crude Protein
DE	Digestible Energy
DM	Dry Matter
DMI	Dry Matter Intake
EE	Ether Extract
EOT	End of Test
FA	Fatty Acid
FAME	Fatty Acid Methyl Ester
FFA	Free Fatty Acid
GC	Gas Chromatography
GE	Gross Energy
LLH-HOG	Low lignin hull, high oil groat
Mcal	Megacalorie
ME	Metabolizable Energy
MPS	Microbial Protein Synthesis
MUFA	Monounsaturated Fatty Acid
NDF	Neutral Detergent Fibre
NE_G	Net Energy of Gain
NE_M	Net Energy of Maintenance
NRC	National Research Council
OM	Organic Matter
P	Phosphorus

P	Probability
PI	Processing Index
PUFA	Polyunsaturated Fatty Acid
RA	Ruminal Acidosis
SARA	Subacute Ruminal Acidosis
SEM	Standard Error of the Mean
SFA	Saturated Fatty Acid
TAG	Triacylglycerol
TMA	Trimethyl Acetic Acid
USFAT	Ultrasound Subcutaneous Fat
USLDA	Ultrasound Longissimus Dorsi Area
VFA	Volatile Fatty Acid
VLDL	Very Low Density Lipoprotein

1.0 INTRODUCTION

Inclusion of cereal grains in feedlot cattle production increases dietary energy density and typically improves the cost of gain in commercial feedlots (Gibb et al. 2009). Cereal grains are concentrated sources of nutrients that can be readily transported long distances and stored for relatively long periods of time. From an economic perspective, cost per unit of energy is an important factor to consider when formulating feedlot diets. The cost per megacalorie (Mcal) of dietary energy almost always favors feeding high-concentrate diets (Brown et al. 2006).

Cattle feeding is a capital intensive, high-risk, low-margin business. To be competitive, cattle feeders must continually assess alternative feeds that may provide an economic advantage in terms of animal performance. In the United States, corn is the predominant grain source in feedlot diets whereas in western Canada and the northwest United States, barley is the most important energy source. In contrast, oat grain has been used to a lesser extent, particularly in finishing cattle diets. This is due to its lower digestible energy (DE) content relative to either barley or corn. One of the reasons for this lower energy value is the fact that the hull of the oat kernel can constitute up to 25% of the total weight of the oat grain (Crosbie et al. 1984). The oat hull is high in lignified fibre, accounting for lower digestibility and poorer nutritional value (Thompson et al. 2000). Of interest is the fact that Thompson et al. (2000) reported that there is considerable variability in the effective ruminal degradability of fibre of hulls that are derived from different oat varieties. In comparison, Du (2008) measured the hull content for six barley varieties (AC Metcalfe, CDC Dolly, McLeod, CDC Helgason, CDC Trey and CDC Cowboy) collected over three years (2003, 2004, and 2005) and determined that hull content varied from 9.4 to 10.7% with a mean value of 10.1%.

Oat also has lower starch content than either barley or corn, a factor that also negatively influences its digestible energy value. It is well known that ingestion of excessive amounts of readily fermentable carbohydrates can increase the incidence of acute and chronic acidosis in feedlot cattle (Owens et al. 1998). Thus, it may be possible that the replacement of barley or corn with oat may reduce digestive disturbances, particularly in high concentrate feeding programs. Another factor in favour of oat as a cereal grain is the fact that it has higher oil content than either barley or corn. This ability of oat to concentrate oil has been manipulated in breeding programs to increase the oil content of the groat (Holland et al. 2001).

Plant breeders at the Crop Development Centre of the University of Saskatchewan have a long standing oat breeding program. One of the objectives of this breeding program was to increase the oil content of the groat in the new oat. Coupled with the work of Thompson et al. (2000), these workers attempted to develop a feed oat that would compete with barley in feedlot growing and finishing programs. Efforts were concentrated on selectively breeding an oat with a low acid detergent lignin (ADL) hull and a high oil groat (LLH-HOG). A prototype line in this breeding program was used by Fuhr (2006) to evaluate its effectiveness in early lactation dairy rations. Milk yield of cows fed the LLH-HOG oat tended (P=0.09) to be higher than that of cows fed a conventional oat variety (Derby) or barley as the cereal grain. Based on a total tract digestibility study with sheep, the DE value of the LLH-HOG oat was 3.55 versus 3.58 Mcal kg^{-1} dry matter (DM) for barley.

There has not been any evaluation of this new oat type with growing or finishing cattle. Recent refinements in the oat breeding program has developed an oat with an ADL content of 1.0% and an oil content of 8.5% or greater. Based on these characteristics, it is hypothesized that the LLH-HOG oat would be equal or superior to barley as a feed grain for growing and finishing cattle and may potentially approach the value of corn grain.

The following literature review focuses on background information related to the inclusion of cereal grains in feedlot cattle diets, including information on unique characteristics of grains, nutrient metabolism (starch and lipid) in ruminant diets, and potential negative effects of feeding high concentrate grain-based diets.

2.0 REVIEW OF THE LITERATURE

2.1. Oat Production in Saskatchewan

Oat is an important cereal crop with annual global production estimated at approximately 25 million tonnes (www.agriculture.gov.sk.ca/oats). Canada is a major supplier of oat grain with annual production of 2.8 to 3.8 million tonnes (www.statcan.gc.ca). Oat is often grown as an alternative to cereal crops such as wheat and barley to supply markets for milling (human food), livestock feed, specialty markets (pony oats) or forage. In Saskatchewan, average annual production has been in excess of two million tonnes, produced on approximately 750,000 hectares (www.agriculture.gov.sk.ca/oats; www.statcan.gc.ca). In comparison, in 2013 barley was seeded on one million hectares producing 4.5 million tonnes (www.statcan.gc.ca).

The climate in Saskatchewan, particularly on the eastern side of the province, is conducive to the production of high quality oat grain. Currently, oat production is characterized by strong market prices and relatively low input prices. This combination contributes to the profitability of oat production where many oat growers are able to produce a high quality oat crop that generates cash flow and improves profitability for their grain farming enterprise. These factors have contributed to increased oat production in the province.

A proportion of the oat crop grown in Saskatchewan is milled to provide products that are suitable for human consumption. These include oatmeal for porridge, oat flour for baby foods and ready- to-eat breakfast cereals (Hoover et al. 2003). βeta-glucan in oat soluble fibre has been identified as the active component that lowers serum cholesterol and reduces the risk of coronary heart disease (Cervantes-Martinez et al. 2001). Oat grain that does not meet milling quality standards can be marketed into the domestic feeding industry in western Canada but must be priced competitively as an energy source with barley and more recently, corn.

2.2. Cereal Grains in Feedlot Diets

Cereal grains differ in their physicochemical properties and as a result have unique feed characteristics that can be utilized to determine their respective feeding value in livestock diets. Protein, fibre and starch content, and the rate and extent of starch degradation are commonly used to characterize these differences. The ruminant digestive system enables the fermentation of

structural carbohydrates to provide energy for microbial protein synthesis (MPS) to support maintenance, growth, reproduction and lactation requirements of the animal (Harmon et al. 2004). However, economic considerations such as the price of grain relative to forage has resulted in cattle being fed high-grain diets to optimize production in intensive production systems such as feedlots (Huntington 1997). Knowledge of the unique properties of feed grains assists in managing ruminant feeding programs, especially in finishing diets where starch provides the majority of the animal's energy intake (Tricarico et al. 2007).

Limited quantities of cereal grain are included in feedlot backgrounding diets to promote muscle deposition while minimizing that of fat (Vaage et al. 1998; Block et al. 2001). In contrast, finishing diets may include as much as 85% cereal grain on a dry matter basis (Wang and McAllister 2000). While grain production may be based on local agronomic considerations such as yield potential and disease resistance, factors such as local availability of grain supply, storage and processing requirements are also considered when selecting an appropriate feed grain for use in feedlot diets. Overriding all of these factors is the importance of economics. Cost per unit of nutrient and subsequent animal performance and efficiency of feed conversion to live weight gain have a major influence on profitability of the cattle feeding industry.

2.2.1. Cereal Grain Processing

Cereal grains are processed to increase their digestibility, as mechanical disruption of the fibrous hull and pericarp increases exposure of the endosperm to microbial attachment and enzymatic digestion by rumen microbes (Koenig et al. 2003; McAllister and Cheng 1996). The method of processing selected depends on the type of cereal grain due to physical differences in the outer layers of grain kernels and in the endosperm of different cereal grains. For the majority of feedlots in western Canada, dry rolling is the method of choice whereas steam flaking is more common in the cattle feeding areas of the United States (Wang and McAllister 2000).

Dry rolling grain involves passing it between two steel, rotating rolls (grooved or smooth). The extent of damage to the kernel is controlled by the characteristics of the kernel and the setting of the roller mill, specifically the amount of tension applied to the rolls (Wang and McAllister 2000). The extent of processing is essentially a balance between sufficient mechanical damage to the outer layers of grain in order to facilitate microbial digestion while

avoiding over processing of kernels, which can lead to excess production of small particles that contribute to rumen acidosis. A grain processing index (PI) is sometimes used to describe the extent of processing. A high degree of processing will produce kernels with finer particle size and lower the volume weight of the grain. Reduced feed intake has been observed in cattle fed extensively processed grain and has been attributed to excessive rates of rumen acid production leading to subacute ruminal acidosis (SARA) (Owens et al. 1998). Comparing the volume weight of processed grain to the volume weight of the unprocessed grain can generate a PI (Yang et al. 2000). Hironaka et al. (1992) reported the optimal PI for feedlot cattle fed dry-rolled barley to be 80 - 85%.

Steam flaking is most commonly used to process corn grain. Steam flaking corn increases ruminal digestion of starch and results in increased ruminal energy supply and utilization from this feed grain. Aggressive grain processing techniques such as steam flaking can break up the starch/protein matrix in the endosperm and can increase energy availability from corn by as much as 18% over feeding of the whole kermel (Zinn et al. 2002). Steam flaking corn also increases the rate and extent of ruminal digestion of starch and increases the energy value of corn compared to dry rolled and whole corn (Theurer et al. 1996). Unlike corn, the homogenous endosperm in barley does not require extensive processing to facilitate microbial digestion. Dry rolling damages the outer layers of the barley kernel sufficiently to expose the starch embedded in the endosperm to microbial digestion (Wang and McAllister 2000).

Research has been quite limited regarding the effect of processing oat grain on digestibility and cattle performance. In an experiment in which restricted levels of wheat, barley oat and hay (4 kg of oat grain (whole or dry-rolled) and 2 kg of hay) were fed to two-year old steers, mean organic matter digestibility increased due to processing from 76.7% to 81.0% (Toland 1976). Based primarily on this early research, Mathison (2008) concluded that rolling oat grain will not improve the digestibility of oat by more than 5% for calves and 10% for cattle up to two or three years of age. Oat grain has a large outer hull relative to barley, but the pericarp of oat is not adhered tightly onto the endosperm as in the barley kernel. The outer hull of the oat and pericarp surrounding the germ and endosperm may be sufficiently damaged during mastication to facilitate microbial attachment to starch granules of oat relative to barley and may account for the smaller improvement in digestibility of dry-rolled oat grain fed to younger cattle (adapted from Wang and McAllister 2000). Zinn (1993) evaluated the influence of processing on

the feeding value of oat for feedlot cattle and observed that steam processing and rolling to produce a coarse flake (0.33 kg L^{-1}) increased the energy value of oat by 7.6% compared to dry-rolled oat grain (0.36 kg L^{-1}). Enhanced ruminal nitrogen efficiency, decreased ruminal methane loss and increased organic matter digestibility were cited as possible explanations for the improved energy value of steam-processed oat.

2.2.2. Corn

Corn (*Zea mays* L.) is the predominant feed grain produced in North America. Two genotypes, flint or dent, differ in their endosperm texture (Philippeau et al. 1999). In western Canada, the relatively short growing season and lack of heat units limits the number of acres seeded to corn. Crop breeding companies such as Monsanto and Pioneer HiBred have been expanding their crop breeding programs to select low-heat-unit corn varieties that are more suitable to western Canada. Excellent animal performance and minimal digestive disorders have resulted in corn being well accepted in feedlot diets (Gray and Stallknecht 1988). The National Research Council (NRC) (1996) assigns NEm and NEg values for corn of 2.18 and 1.50 Mcal/kg dry matter (DM), respectively. Corn grain contains a high proportion of starch that provides the majority of dietary energy to finishing beef cattle (Tricarico et al. 2007). Philippeau et al. (1999) reported the mean starch content of dent and flint corn at 68.0% and 67.1%, respectively. Hererra-Saldena et al. (1990) reported a higher value for the starch content of corn at 75.7% but noted that only 13.1% of the starch was degraded following a 60 minute *in vitro* incubation. The lower starch degradability rate compared to other cereal grains such as barley and oat may be the result of the protein matrix associated with starch granules in the endosperm (Rooney and Pflugfelder 1986, McAllister et al. 1994).

In dent corn, there are two distinct regions in the endosperm, the floury and the horny (corneous) endosperm (Wang and McAllister 2000). Starch in the horny endosperm is tightly embedded in the protein matrix and is quite resistant to microbial digestion (Wang and McAllister 2000). This protein matrix is extremely resistant to attachment and penetration by microorganisms which results in a lower rate of ruminal starch fermentation compared with other cereal grains such as wheat and barley (McAllister et al. 1994).

Studies comparing the performance of cattle fed barley or corn generally shows that corn is a superior feed grain for cattle (Owens et al. 1997). Yang et al. (1997) observed an increase in feed intake and higher milk production of dairy cows fed a corn diet compared to cows fed a barley diet. The large proportion of starch in the endosperm of the kernel provides a good substrate for ruminal fermentation. Although the rate of ruminal starch degradation may be lower than that of other feed grains such as barley and oat, enhanced ruminal starch digestion through the use of steam flaking can result in improved animal performance (Zinn 1990).

Corn is higher in energy but its protein content is typically lower than that of barley (9.0 vs. 13.2% (DM basis), NRC 1996). Additional protein must be supplemented in corn-based feedlot diets compared to barley-based rations. As identified by Galyean (1996), crude protein (CP) in typical beef cattle finishing diets exceeds 12% of diet DM and improved animal performance is observed when supplemental CP is derived from ruminally degraded vs. undegraded protein sources. The cost of additional protein supplementation must be taken into account when evaluating the cost-effectiveness of substituting corn for barley as the grain source in feedlot diets.

2.2.3. Barley

In western Canada and the northwest United States, barley (*Hordeum vulgarae* L.) is an important feed grain (Kincheloe et al. 2003). Although corn is generally considered a superior feed grain as a result of its higher energy content, there are reports of similar animal performance and feeding value for barley and corn (Kincheloe et al. 2003; Beauchemin and Koenig 2005). Block et al. (2001) observed average daily gain (ADG) of 1.86 and 1.85 kg d^{-1} in two feedlot finishing trials where steers were fed diets containing 73.3% and 77.5% barley, respectively. Boss and Bowman (1996) reported the ADG at 1.30 kg d^{-1} for steers fed an 80% barley-based finishing diet. The reported NEm and NEg values for heavy barley grain are 2.06 and 1.40 Mcal/kg DM, respectively (NRC 1996). Differences in energy value between corn and barley grain can be attributed to the lower starch and higher fibre content of barley relative to corn. The starch content of barley has been reported to be 64.3% (DM basis) (Herrera-Saldena 1990), 53.2% (Yang et al. 1997) and 44.3%-50.0% (Boss and Bowman (1996). While the starch content of barley is lower than corn, the starch in barley is more rapidly degraded in the rumen. Herrara-

Saldena (1990) reported that 18.1% of total starch in barley was degraded following a 60-minute *in vitro* incubation. Rapid starch degradation can increase the incidence of disorders such as bloat, acidosis, founder and abscessed livers in beef cattle (Huntington 1997). Barley kernels have an outer hull which is high in fibre content. This outer hull also contributes to its lower digestible energy content relative to corn grain (Yang et al. 1997). In addition, the endosperm of barley is surrounded by a tough pericarp which, if left intact, reduces digestibility of the seed leading to reduced energy availability because of resistance of the pericarp to bacterial attachment (Wang and McAllister 2000).

2.2.4. Oat

Oat grain (*Avena sativa* L.) is reported to be lower in energy than barley and corn primarily due to a larger proportion of hull relative to other cereal grains. The NRC (1996) assigns NEm and NEg values of 1.85 and 1.22 Mcal/kg respectively, for heavy oat. Lower digestible energy has typically restricted the use of oat grain to feedlot diets where maximum animal performance is not desired, such as backgrounding diets, diets for starting cattle on feed or creep feeds. The common perception is that the hull and higher fibre content of oat compared to barley or corn will minimize feeding problems as these animals adapt to grain-based feedlot diets. Approximately 25% of the weight of the oat kernel is hull (Crosbie et al. 1984). Typical oat hulls contain 5.5-6.0% ADL which has a negative association with hull digestibility (Thompson et al. 2000). In addition to lignin, the hull is characterized by the content of cellulose and arabinoxylans (Knudsen 1997). Oat grain typically contains less starch (58.1%) compared to barley (64.3%) or corn (75.7%) (Herrera-Saldana et al. 1990). Oat starch has approximately 25-30% amylose and does not appear to have any waxy mutants (Peterson 2004). Rate of starch degradation has been reported to be very high for oat. Herrera-Saldena et al. (1990) reported that 28.0% of total starch in oat grain was degraded following a 60-minute *in vitro* incubation. As reported by Hoover et al. (2003), oat starch is characterized by smaller amylose chain length and smaller granule size. These characteristics may be responsible for the increased rate and extent of ruminal starch degradation observed by Herrera-Saldana et al. (1990).

The lipid fraction of the oat kernel is present in the groat and consists primarily of palmitic (C16:1), oleic (C18:1) and linoleic (C18:2) acids (Peterson 2004). Despite increased

concentration of the higher energy-yielding lipid fraction relative to other cereal grains, the energy value of oat is typically lower as a result of the lower digestibility of the fibrous hull.

Since oat-based finishing diets are typically lower in energy compared to barley- or corn-based finishing diets (Johnson and Boyles 1991), cost per unit of energy and desired rate of animal weight gain are important considerations when choosing to incorporate oat into feedlot cattle diets. Johnson and Boyles (1991) estimated that oat grain is worth only approximately 85% of the value of corn or barley (per tonne) when fed at more than 50% of the grain portion of the diet for finishing cattle.

2.3. Starch in Ruminant Diets

2.3.1. Starch in Cereal Grains

Starch is the most important of the storage carbohydrates in plants (Van Soest 1994). Starch granules are composed of amylopectin (α-1,4 and α-1,6 linkages) and amylose (α-1,4 linkages) and are concentrated in the endosperm of grain kernels (Huntington 1997). The proportion of amylose and amylopectin can vary between cereal grains and to a large extent is controlled by genetics. While the starch content of corn is higher (75.7%, DM) than that of barley (64.3%, DM) and oat (58.1%, DM), the rate of starch degradability determined *in vitro* using a 60-minute incubation with glucoamylase was found to be the inverse, being highest for oat (28%) followed by barley (24%) and then corn (9%) (Herrera-Saldana et al. 1990). While it is desirable to maximize the extent of starch fermentation in the rumen to optimize energy availability for MPS, the rate of starch digestion is an important consideration as too rapid a rate of starch digestion can result in digestive disturbances such as bloat and/or acidosis (Koenig et al. 2003).

2.3.2. Ruminal Starch Digestion

Starch digestion is an important consideration when evaluating feeds for use in ruminant diets. Starch in most cereal grains is utilized well by ruminants, being almost completely digested over the total digestive tract (Philippeau et al. 1999). However, the rate and extent of ruminal starch fermentation varies with grain source and grain processing method (Owens et al.

1997; Herrera-Saldena 1990; Zinn 1993; Huntington 1997). Within the normal range of rumen function, the amount of starch digested in the rumen is a linear function of starch intake (Huntington et al. 2006).

A key step in starch digestion in the rumen is bacterial attachment to feed particles. Approximately 75% of starch digestion is accomplished by bacteria that are loosely or tightly adhered to feed particles (McAllister et al. 1994). Amylolytic bacteria produce enzymes that hydrolyze the α-1,4 and α-1,6 bonds of amylose and amylopectin (Huntington 1997). In addition to ruminal bacteria, ruminal protozoa may ingest starch granules (with or without bacteria attached) and influence the rate and extent of starch digestion in the rumen. The importance of grain processing should not be overlooked as an intact pericarp may be largely resistant to bacterial attachment and result in incomplete ruminal starch digestion (McAllister et al. 1994).

2.3.3. Intestinal Starch Digestion

There is considerable interest in the energetic efficiency of starch digestion in the small intestine due to pregastric fermentation losses of 13-18% of gross energy (GE) (Harmon et al. 2004). Methane emissions result during microbial fermentation of feed in the rumen and represent a loss of productive energy for the animal (Beauchemin and McGinn 2005). Johnson et al. (2000) reported energy lost as enteric methane from 2% to nearly 12% of GE. Level of feed intake and diet composition are the major factors that determine energy loss through enteric methane produced during ruminal fermentation (Johnson et al. 2000).

On average, 5% to 20% of dietary starch consumed is digested postruminally and that most of the digestion occurs in the small intestine (Huntington 1997). This worker summarized digestibility coefficients from experiments conducted during 1986-1995 and reported that post-ruminal starch digestibility for dry-rolled corn, barley and oat was 16.2% ± 6.7, 13.7% ± 3.8 and 5.6% (no SD reported) respectively.

Starch digestion in the small intestine of the ruminant is an enzymatic process similar to that in other mammals (Huntington 1997). Pancreatic secretion of α-amylase hydrolyzes internal α-1,4 glucosidic bonds of amylose and amylopectin into dextrins and oligosaccharides of two to three glucose units (Harmon et al. 2004). Approximately 70% of starch digested in the small intestine appears as glucose in the bloodstream (Huntington et al. 2006). Several processes may

be involved in the transfer of glucose from the lumen of the small intestine to the bloodstream, but the main mechanism appears to rely on active transport involving the sodium-glucose transporter located in the intestine (Harmon 2009). Glucose crosses the brush-border membrane via the sodium-dependent glucose transporter, SGLT1. This transporter is a high-affinity glucose transporter that couples glucose transport to an inwardly directed sodium gradient. Harmon (2009) noted that the expression of SGLT1 increased 1.3- fold in steers infused abomasally with starch. It is interesting to note that another glucose transporter, GLUT2, was observed to have increased six-fold in this same experiment. Harmon (2009) hypothesized that the addition of GLUT2 as a potential mechanism of mucosal transport may be the key to explaining previous work studying SGLT1 in ruminants, but further research is required.

2.4. Ruminal Acidosis

In finishing diets, starch provides the majority of the animal's energy intake (Tricarico et al. 2007). A large supply of rapidly fermentable carbohydrate in the rumen increases the risk of ruminal acidosis (RA) and can negatively affect feed intake in feedlot cattle. Ruminal acidosis is a nutritional disorder of feedlot and dairy cattle that has resulted from the inclusion of cereal grains into ruminant diets to supply dietary energy to meet the demands of intensive ruminant production (Blanch et al. 2009). Animals can exhibit acute or subacute symptoms that range from lethargy, dehydration and reduced feed intake in mild cases to shock and death in severe cases (Owens et al. 1998). Low or erratic feed intake is often associated with subacute ruminal acidosis (SARA) (Galyean and Rivera, 2003) but it is difficult to assess and definitively link lower feed intake directly to the effects of SARA.

Feedlot finishing diets contain a large proportion of cereal grains that supply readily fermentable non-fibre carbohydrates and increase the risk of RA in cattle due to rapid production and accumulation of volatile fatty acids (VFA) and lactate. (Nocek et al. 1997; Blanch et al. 2009). Lactic acid accumulates in the rumen when bacteria such as *Megasphera elsdenii* and *Selenomonas ruminantium* capable of utilizing lactic acid are outnumbered by lactobacilli and *Streptococcus bovis* (a major lactate-producing bacteria). Lactic acid is a very potent acid and if production/accumulation is excessive, rumen pH will drop (Nocek 1997). Mean ruminal pH of feedlot cattle fed high-grain diets is usually between 5.5 and 6.5 (Nagaraja and Lechtenberg

2007; Schwartzkopf-Genswein et al. 2003). As rumen pH drops below 5.6, the absorption of VFA increases (Nagaraja and Titgemeyer 2007; Penner et al. 2009). This is due to the fact that as the VFA's become more undissociated, in theory the rate of passive diffusion increases (Nagaraja and Titgemeyer 2007). The actual importance of passive diffusion, however, is open to question as VFA absorption also occurs in the dissociated state in exchange for bicarbonate and other anions (Penner 2009). A factor that further enhances rumen pH drop is that the microbial population also shifts toward lactic acid production (Nagaraja and Titgemeyer 2007). Lactate is about ten times stronger than VFA (pKa 3.9 vs 4.9) and the accumulation of lactic acid in the rumen further decreases rumen pH (Nagaraja and Titgemeyer 2007; Penner et al. 2009). In RA, lactic acid production overwhelms the lactic acid fermenters and acid-tolerant lactobaccili species. increases the production of lactate, which further reduces rumen pH (Nagaraja and Lechtenberg, 2007). Accumulation of the acids can damage the epithelial lining of the rumen and blood pH begins to decrease (Owens et al. 1998). Dehydration, decreased cardiac output and reduced renal blood flow can result in shock and in severe cases, death (Nocek 1997). Even if the animal recovers from a severe case of acidosis, depending on the extent of the decline in rumen pH, long-term effects may include decreased nutrient absorption due to rumen wall damage (Owens et al. 1998; Penner et al. 2010) as well as issues with liver abscesses and lameness. Owens et al. (1998) reported that clinical diagnosis of systemic acidosis requires blood pH to fall below 7.35. Penner et al. (2007) identified that RA was considered to occur when ruminal pH was <5.8. Ruminal acidosis was further partitioned into: 1) mild RA (5.8 > ruminal pH > 5.5), 2) moderate RA (5.5 > ruminal pH > 5.2), and 3) acute RA (ruminal pH < 5.2). The amount of time that rumen pH is below a threshold is a consideration in the assessment of RA. In a study that induced SARA in Jersey steers, Gozho et al. (2005) observed that two steers exhibited SARA after rumen pH remained below 5.6 for 187 and 174 min d^{-1}, respectively, on days four and five of the study. These workers proposed that SARA occurs when rumen pH is depressed to levels ranging from 5.2-5.6 for more than three hours per day, and noted that a reduction in feed intake due to SARA is likely to occur only when this threshold has been met or exceeded.

The effect of grain source on the incidence of acidosis may be of particular interest for this study. The conversion of starch to glucose varies with grain source and the rate and extent of cereal grain digestion is typically positively correlated (Owens et al. 1997). As discussed

previously, oat grain has a rapid rate of starch degradation and may induce acidosis in feedlot cattle more than alternative grains such as barley and corn.

The effect of lipids on mitigating acidosis has been investigated. Huffman et al. (1992) hypothesized that the inclusion of supplemental fat could reduce the incidence of acidosis by coating the grain and altering the rate and/or extent of ruminal starch digestion. Krehbiel et al. (1995) conducted several animal feeding experiments using various levels and sources of fat and concluded that fat was ineffective in preventing SARA in cattle fed dry-rolled, corn-based finishing diets. As the level of tallow increased in the finishing diet from 0% (control) to 8%, ruminal pH declined quadratically ($P < 0.05$) (Krehbiel et al. 1995). These researchers concluded that adding up to 6% fat to high-concentrate finishing diets may actually reduce ruminal pH compared with not adding supplemental fat.

2.5. Lipids in Ruminant Diets

2.5.1. Chemistry of Lipids

Lipids are a group of naturally occurring organic compounds that have a hydrocarbon chain as their dominant feature. Carbon atoms may be connected by a single bond (saturated linkage) or double bond (unsaturated linkages.) A hydrocarbon chain with one unsaturated linkage is referred to as monounsaturated whereas hydrocarbon chains with more than one unsaturated linkage are referred to as polyunsaturated. Christie (2013) defines lipids as "fatty acids (FA) and their derivatives, and substances related biosynthentically or functionally to these compounds." Previously, lipids were defined by their solubility in non-polar organic solvents (e.g. ether, chloroform, benzene, and hexane) and their insolubility in polar solvents such as water, but Christie (2013) indicates that this would overlook many substances that are now regarded as lipids that may be almost as soluble in water as in organic solvents. Common lipids in nature are comprised mainly of FA and may be classified based on their chemically functional backbone. Fahy et al. (2005) provides a detailed classification system for lipids and a summary of this system is presented in Table 2.1.

Table 2.1. Lipid categories and examples

Category	Abbreviation	Example
Fatty Acids	FA	Dodecanoic acid
Glycerolipids	GL	1-hexadecanoyl-2-(9 *Z*-ocatacenoyl)-*sn*-glycerol
Glycerophospholipids	GP	1-hexadecanoyl-2-(9 *Z*-ocatacenoyl)-*sn*-glycero-3-phosphocholine
Sphingolipids	SP	*N*-(tetradecanoyl)-sphing-4-enine
Sterol lipids	ST	cholest-5-en-3β-ol
Prenol lipids	PR	2*E*,6*E*-farnesol
Saccharolipids	SL	UDP-3-*O*-(3*R*-hydroxy-tetradecanoyl)-αD-N-acetylglucosamine
Polyketides	PK	Aflatoxin B_1

Source: Fahy et al. (2005)

Lipids can be broadly subdivided into simple and complex groups. Members of the simple lipid class yield no more than two types of products on hydrolysis (triacylglycerols) and complex lipids yield three or more products on hydrolysis (glycerophospholipids and glycolipids) (Fahy 2005; Christie 2013.)

Most fats and oils used in livestock diets and the lipid fraction of plant and animal products consist mainly of triacylglycerols (TAG). Triacylglycerols consist of a glycerol moiety esterified to three hydrocarbon chains of varying length and degree of saturation (Christie 2013). Fatty acids are the major constituent of lipids and are an important energy storage reservoir in living organisms (Van Soest 1994). Common fatty acids of plants are C16 and C18 hydrocarbon chains with zero to three double bonds of *cis* configuration (Christie 2013). In animal tissues, FA with a wider range of even numbered chain-lengths and up to six double bonds in *cis* and/or *trans* configuration may be present (Christie 2013).

2.5.2. Lipid Sources for Ruminants

Ruminants can metabolize lipids from a variety of feedstuffs to obtain dietary energy. In forages, lipids are present in leaf tissue as glycolipids. Glycolipids can be further characterized as galactolipids (present in chloroplasts) and phospholipids (present in cell membranes) (Van Soest 1994). Forage-based diets for ruminants typically contain 2-5% lipids, of which approximately 50% is FA (Doreau and Ferlay 1994). The FA concentration of forage lipid is rarely more than 1.5% of the forage DM (Zinn and Jorquera 2007). The FA in glycolipids are typically polyunsaturated and consist primarily of linoleic acid (*cis*-9 *cis*-12 18:2 n-6) and linolenic acid (C18:3 n-3) (Van Soest 1994).

Cereal grains are generally low in oil content but the proportion of FA in the lipid fraction is typically higher than in forages (galactolipids) as FA in grain are present as TAG (Van Soest 1994). Through selective plant breeding, grain cultivars with elevated oil content have been developed. Grain cultivars with elevated oil content typically have a much larger seed embryo and as the embryo partially displaces the endosperm, these cultivars have proportionally less starch (Owens et al. 2002). High oil corn varieties have been developed and in the United States, cropped acreage devoted to these specialty corn hybrids increased from 400,000 acres in 1996 to 1.2 million acres in 1999 (U.S. Grains Council 1999).

Oat grain is typically higher in oil compared with other cereals and can vary from 3 to 11% of the grain weight (Banaś et al. 2007). Typical oat cultivars contain approximately 4 to 5% oil content (Racz and Rossnagel 2004). Oat grain is unique in the fact that most of the oil is widely dispersed throughout the endosperm (Price and Parsons, 1979). In a selective oat breeding study, Banaś et al. (2007) concluded that the differences in oil content between a medium-oil and a high-oil cultivar was almost completely confined to an increase in the oil content of the endosperm in the high-oil cultivar. Holland et al. (2001) were successful in selecting for high groat oil from a broad-based oat population, and these workers identified improved feed value for livestock as one of the positive outcomes from the breeding program.

Triacylglyerols are the major class of lipids in cereal grains (Palmquist and Jenkins 2003). The TAGs are lipid storage structures and typically consist of 90% fatty acids and 10% glycerol. The energy value of the glycerol moiety (10-11% of the triglyceride by weight) is approximately the same as non-structural carbohydrates, whereas the fatty acids contribute to the

high energy value of the lipid (Palmquist and Jenkins 2003). Forages and cereal grains which comprise typical ruminant diets, often contain linoleic acid (*cis*-9 *cis*-12 18:2 n-6), linolenic acid (*cis*-9 *cis*-12 *cis*-15 C18:3 n-3,) and oleic acid (*cis*-9 n-9 C18:1) (Buccioni et al. 2012).

Supplemental fats such as inedible fats and oils are a concentrated source of dietary energy and have been used in livestock diets to improve palatability and feed efficiency and control dust. Tallow and recycled restaurant grease (yellow grease) are the principle sources of fat used in animal feeds and represent approximately 80% of total inedible fats and oils used in the livestock feeding industry (Zinn and Jorquera, 2007). Net energy values of supplemental animal fat (e.g. tallow) for feedlot cattle are 6.00 and 4.50 Mcal/kg DM for maintenance and gain, respectively (NRC, 1996). Supplemental feed fats are composed mainly of FA (90%) (Zinn 1989). Particular attention to fat quality is important. Moisture content, insoluble impurities, unsaponifiables, total FA, free fatty acids (FFA), titre, iodine value and initial peroxide value are factors used to assess supplemental fat quality in livestock diets (Zinn and Jorquera 2007).

Microbial lipids are another source of energy for ruminants. Demeyer and Doreau (1999) estimated that rumen bacteria can contribute as much as 17% of the lipid flowing from the rumen to the small intestine. Rumen bacteria can synthesize FA (mainly C16:0 and C18:0) *de novo* from carbohydrate sources in the rumen (Jenkins 1993). Phospholipids in microbial membranes are the main lipid storage component associated with *de novo* lipid synthesis by ruminal bacteria.

2.5.3. Lipids in Ruminant Diets

The use of lipid as a dietary energy source for cattle seems contrary to the evolutionary development of these animals. Domesticated ruminants evolved to maximize the utilization of cellulosic carbohydrates as energy sources (Van Soest 1994). Early research related to nutrition of farm animals identified lipids as compounds existing in natural feedstuffs. The inclusion of lipids in ruminant diets has received considerable attention in the last number of decades for several reasons including:

1) Improvements in genetics and livestock management have increased productivity of ruminants;
2) In order to sustain increased productivity, increased dietary energy is required; and

3) Excess starch intake can increase the risk of metabolic disorders such as acidosis in feedlot cattle.

2.5.3.1. Positive Effects of Lipids in Ruminant Diets

Fat is typically added to ruminant diets primarily as a source of energy, but may also be used to control dust and increase the palatability of the diet (Azain 2004; Zinn and Jorquera 2007). Fat is an energy-dense nutrient (9.0 Mcal kg^{-1} gross energy) and the addition of lipid can increase dietary energy content at low inclusion levels (Mir et al. 2006). The NRC (1996) assigns an ME value of 6.40 Mcal kg^{-1} for tallow compared to 3.04 Mcal kg^{-1} for heavy feed barley. This energy-dense characteristic is particularly useful when fat is incorporated into diets where a high demand for energy is required, such as in lactating dairy cattle and finishing beef cattle (Mir et al. 2006). In high-producing milk cows, the inclusion of 3-5% fat increases energy intake, while reducing the amount of starch fed, which increases the forage to concentrate ratio and can assist in prevention of milk fat depression (Palmquist and Jenkins 1980). During periods of heat stress, decreased feed intake, increased sweating, increased respiration rate and a shift in blood flow to the skin surface (vasodilation) are physiological responses by cattle in an attempt to restore thermal balance (West 1999). Decreased feed intake has a negative effect on milk production through reduced nutrient intake. Increasing the energy concentration of lactating cow diets through the addition of fat may be more satisfactory than feeding additional grain during periods of heat stress. The lower heat increment associated with the feeding of fat compared to forage and concentrates may reduce metabolic heat production and increase retained energy for milk production (West 1999).

In finishing cattle diets, the addition of fat has been shown to improve animal performance by increasing the energy density of the diet (Hess et al. 2008). Zinn (1989a) reported that increasing the level of supplemental fat (yellow grease and blended animal-vegetable fat) from 0% to 8% in finishing diets for feedlot steers resulted in a linear improvement in rate of weight gain, feed conversion and net energy value of the diet.

In recent years, ruminant production is under closer public scrutiny for its perceived contribution to climate change. Enteric ruminal fermentation produces methane, a significant source of greenhouse gases, which is released to the atmosphere during eructation. Beauchemin

et al. (2009) estimates that up to 17% of the world's methane emissions comes from livestock. The addition of lipid through the inclusion of oilseeds or edible oils in ruminant diets may reduce methane gas emissions produced during rumen fermentation (Beauchemin and McGinn 2005). The inclusion of 5% sunflower oil into the diet of growing beef cattle decreased methane emissions by 22% (McGinn et al 2004). The effects of dietary lipid addition on methane production appear to involve more than one factor. Primarily, the addition of lipid decreases the amount of ruminally fermentable substrates, but lipid addition may also increase propionate production and inhibit protozoa development in the rumen (Johnson and Johnson 1995).

There is considerable interest in altering the fatty acid profile in animal products for improved human health (Azain 2004). The primary omega-3 FA of interest are α-linolenic, eicosapentaenoic and docasahexaenoic which are less inflammatory, cause vasodilation and inhibit platelet aggregation (Azain 2004). As reported by Basarab et al. (2007), several researchers have demonstrated that conjugated linoleic acids have been identified as having anitioxidative and anticarcinogenic properties in human health and are formed in the rumen during ruminal biohydrogenation of linoleic acid.

2.5.3.2. Negative Effects of Lipids in Ruminant Diets

As reported by Zinn and Jorquera (2007) adapted cattle can tolerate up to 6% supplemental fat in diets without depressing growth performance. The inclusion of supplementary fat, particularly fat sources containing high levels of PUFA, may have negative effects on rumen fermentation. Diets high in PUFA have been reported to have potent antimicrobial effects and inhibit ruminal fermentation (Jenkins 1993). Reduced protozoal and bacterial growth and metabolism of cellulolytic strains have been observed when high levels of PUFA are fed to ruminants (Chilliard 1993). Van Soest (1994) reported that in general, all gram-negative bacteria are inhibited by excess dietary PUFA.

Dry matter intake has been shown to be negatively affected by the addition of lipids to ruminant diets. Andrae et al. (2000) observed an 8.5% reduction in DMI in steers fed finishing diets containing high-oil corn compared to steers fed the control corn diet. In addition, the ratio of *n*-6 to *n*-3 FA in diets of early lactation cows may affect DMI in cattle. Santos et al. (2012) demonstrated that DM intake increased linearly (P=0.05) with reducing the ratio of *n*-6 to *n*-3 FA

in the diet. These workers determined that DM intake was greatest for a diet with a ratio of 4 parts of *n*-6 to 1 part of *n*-3 in the diet.

Dry matter intake is likely determined by integration of signals in brain satiety centres (Allen 2000). Allen et al. (2009) report that several mechanisms may contribute to this negative response due to the increase in intake of dietary FA. Decreased diet palatability and the release of satiety-inducing gut peptides may be responsible for the negative effect on DMI. These workers note that persistent depression of intake for ruminants in a lipolytic state (transition dairy cows and stressed beef calves arriving at feedlots) may be due to elevated liver energy status resulting from oxidation of non-esterified FA mobilized from fat depots. This may provide some evidence to support the hepatic oxidation theory of feed control in ruminants. Allen (2000) suggests that supplemental dietary fat may increase ruminal distention as a result of a reduced rate of passage of digesta from the rumen, which may stimulate tension receptors and suppress feed intake. In addition, fat stimulates the production of cholesytokinin, a hormone that when released contributes to satiety in animals by inhibiting gastric emptying (Allen 2000).

The effect of dietary lipid addition on meat should also be considered when incorporating high levels of supplemental fat in livestock diets. Animal products enriched with omega-3 FA may exhibit a decrease in the firmness of muscle and fat tissue, a reduction in shelf life, and development of off-flavors in meat products (Wood and Enser, 1997).

2.5.4. Lipid Metabolism in the Rumen

Dietary lipids are modified extensively during rumen metabolism (Hess et al. 2007). Lipid metabolism in the rumen is a step-wise process. During the first process called lipolysis, microbial lipases hydrolyze the ester linkages of lipids (TAG, phospholipids, galactosylglycerides and sterol esters) and release fatty acids (Jenkins et al. 2008). Extracellular bacterial lipases produced by *Anaerovibrio lipolytica* and to a lesser extent, *Butyrivibrio fibrosolvens,* are responsible for the hydrolysis of ester linkages (Baldwin and Allison 1983). As reported in Bauman et al. (2003), *A. lipolytica* hydrolyzes TAG and *B. fibrosolvens* hydrolyzes phospholipids and glycolipids. The extent of hydrolysis of unprotected lipids in the rumen is high (85-95%) and occurs rapidly (Bauchart et al. 1990). Glycerol, galactose and free fatty acids (FFA) are the end products of lipolysis in the rumen. Glycerol and galactose are converted to

short-chain VFA, mainly propionate and butyrate (Doreau and Ferlay 1994). Free fatty acids (FFA) are then subjected to a second process in the metabolism of lipids in the rumen.

During the second phase of lipid metabolism in the rumen, unsaturated FFA are biohydrogenated to more saturated end products (Jenkins 1998). Biohydrogenation is a process that converts unsaturated FA to saturated FA through a reduction in the number of double bonds on the carbon chain of the FA (Jenkins et al. 2008). A number of intermediary isomers are produced (*cis* and *trans*) as unsaturated FA are biohydrogenated. Unsaturated FA with 18 carbons are transformed to a variety of treinoic, dienoic and monoenoic isomers as they are biohydrogenated (Bauman et al. 2000). Complete biohydrogentation of 18 carbon unsaturated FA results in the formation of stearic acid (C18:0) (Jenkins 1993). It is believed that biohydrogenation is a defense mechanism in ruminants to protect against the toxic effects of polyunsaturated FA on rumen microbes and the resulting inhibition of ruminal fermentation (Jenkins et al. 2008).

Rumen bacteria involved in biohydrogenation are classified into two groups, A and B (Bauman et al. 2003). Both group A and B bacteria hydrogenate linoleic and linolenic acids to a key intermediary, *trans*-11 C18:1 (vaccenic acid) but only Group B bacteria can fully hydrogenate vaccenic acid to the saturated end product, C18:0 (stearic acid) (Bauman et al. 2003). *Butyrivibrio* spp. and *Clostridium proteoclasticum* are involved in biohydrogenation of linoleic and linolenic acids to vaccenic acid, but only *C. proteoclasticum* is involved in the complete biohydrogenation to C18:0 (Jenkins et al. 2008). The *cis*-9, *trans*-11 conjugated linoleic acid (CLA) is an important isomer produced during biohydrogenation of linoleic acid, as CLA isomers are reported to be anticarcinogenic (French et al. 2000). The biohydrogenation pathway of linoleic acid is illustrated in Figure 2.1.

As reported by Doreau and Ferlay (1994), biohydrogenation by bacteria only occurs on FFA adsorbed on feed particles or microbial cells. Hydrogenation takes place at a slower rate than hydrolysis, is quite extensive but always less than hydrolysis (Doreau and Chilliard 1997). Few polyunsaturated FA remain in the rumen following biohydrogenation.

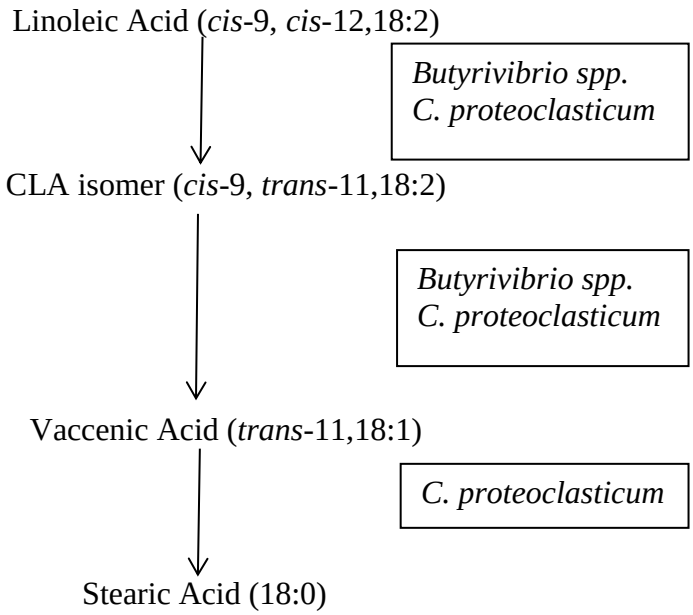

Figure 2.1. Biohydrogenation pathway of linoleic acid
(adapted from Harfoot and Hazelwood 1988)

2.5.5. Lipid Absorption in the Small Intestine

The capacity of ruminants to absorb FA is high (Doreau and Ferlay 1994). As much as 90% of the dietary lipids entering the duodenum are non-esterified saturated FA adhering to feed particles (Doreau and Ferlay 1994). The balance of the lipids in postruminal digesta consists primarily of microbial phospholipids and small amounts of triglycerides or fatty acids of protected fat sources (Bauchart 1993). Prior to FA absorption by the intestinal mucosal cells, desorption of fatty acids from the feed particles must occur. Micelles containing dissolved FA are formed in the small intestine of cattle. Bile production by the gall bladder relative to the quantity of saturated fatty acids present in the duodenum appears to be rate limiting for fatty acid digestion (Plascencia et al 2004; Zinn and Jorquera 2007). Zinn and Jorquera (2007) reported a linear decrease in the energy value of fat when fat intake exceeded 0.96 g kg BW^{-1}, possibly resulting from limited bile production capacity. As reported in Bauman et al. (2003), bile salts and lecithin are present in bile and enzymes secreted by the pancreas convert the lecithin to lysolecithin. The interaction of lysolecithin with bile salts produces the soluble micellar phase containing dissolved fatty acids (Doreau and Chilliard 1997).

The epithelial cells in the jejunum absorb the micelles with 15-25% of FA absorbed in the upper jejunum and 55-65% absorbed in the middle and lower jejunum (Bauchert 1993). Following absorption, FA are re-esterified into TAG and incorporated, along with phospholipids, into apolipoproteins (specialized proteins) and are divided into five major density classes that reflect their relative lipid-protein content (Bauchart 1993: Doreau and Chilliard 1997). These include chylomicrons, very low density lipoproteins (VLDL), intermediate density lipoproteins, low density lipoproteins, and high density lipoproteins (Bauchart 1993). Triacylglycerides and phospholipids are incorporated into chylomicrons and VLDL in epithelial cells of the small intestine and are secreted into intestinal lymph vessels and directly enter the blood in the circulatory system for use by body tissues for fat storage, milk fat production or oxidation for energy production (Doreau and Ferlay 1994). As reported by Bauchart (1993), chylomicron production may be stimulated by increased dietary PUFA compared to saturated FA.

2.6. Development of a Low Lignin Hull, High Oil Groat Oat

The development of high-oil oat cultivars depends on selection of genotypes with a combination of high oil content, good oil quality and desirable agronomic characteristics (Holland et al. 2001). Plant breeders can identify desirable traits in grain and utilize breeding techniques to select for these characteristics. Frey and Holland (1999) demonstrated that selectively breeding for increased groat-oil content in oat was possible following nine cycles of recurrent selection from a broad-based oat population. The intent was to improve the feeding value of oat grain for livestock and potentially develop oat as an oilseed crop to enhance the economic value of oat (Holland et al. 2001).

Plant breeders also can selectively lower acid detergent lignin (ADL) content in the hull from different oat genotypes. Thompson et al. (2000) performed ruminal kinetic studies on hulls of varying ADL content. These workers demonstrated increased *in situ* fibre (ADF and NDF) digestibility in hulls from low lignin oat varieties in comparison to regular oat hulls. Hulls from ten oat varieties were evaluated to determine differences in chemical composition and ruminal degradability. Hulls derived from the variety AC Assiniboia had lower ($P<0.05$) ADL (13 g kg^{-1}) and a higher ($P<0.05$) *in vitro* dry matter disappearance (682 g kg^{-1}) relative to the other nine varieties (Thompson et al. 2000).

Using the AC Assiniboia variety as the basis for the plant breeding program, the Crop Development Centre at the University of Saskatchewan has successfully combined the characteristics of a low lignin hull and high oil groat (LLH-HOG) oat in the development of a new oat which may result in a significant improvement in feed value relative to other oat varieties. The goal of the plant breeding program was to develop a superior feed grain oat that is characterized by a highly digestible, low lignin hull, a high fat (>8%) groat, and premium agronomic performance. The combination of a high oil groat and low ADL hull should result in the development of an oat with higher energy content and improve the feeding value of oat in ruminant diets.

Fuhr (2006) evaluated an early prototype of the LLH-HOG oat in diets fed to sheep and lactating dairy cattle. He demonstrated that milk production in cows fed a diet containing the LLH-HOG prototype was comparable to milk production in cows fed diets containing conventional oat or barley. Based on nutrient digestibility studies involving sheep, Fuhr (2006) estimated that the digestible energy (DE) value of the new LLH-HOG prototype at 3.55 Mcal kg^{-1} DE compared to CDC Dolly barley at 3.58 Mcal kg^{-1} and concluded that the energy value of the new oat was similar to that of barley.

2.7. Summary

Cattle feeders continue to look for alternative sources of feed grain that will improve animal performance or reduce the cost of gain in feedlots. The evaluation of an alternative feed grain for suitability as a ruminant feed must consider several characteristics of the grain. Feed grains can be characterized by fibre and protein characteristics, starch content and the rate and extent of ruminal starch degradation, and lipid composition. Characterization of a feedstuff can involve chemical analysis, digestibility and rumen metabolism studies, rumen kinetic studies and feeding trials. From a practical perspective, the new feed grain should be evaluated against a grain such as barley that is typically used in feedlot diets in western Canada.

The Crop Development Centre at the University of Saskatchewan has successfully combined the characteristics of a low lignin hull and high oil groat in the development of a new oat which may result in a significant improvement in feed value relative to other oat varieties, but there has been no evaluation of the suitability of the LLH-HOG oat grain in feedlot cattle

diets and few studies have evaluated oat grain in finishing diets. It is hypothesized that the due to the high oil content of the groat and the low lignin nature of the hull, the performance and nutrient utilization of cattle fed diets containing this new oat will equal or exceed that of cattle fed diets containing barley or corn.

To test this hypothesis, a series of experiments was carried out with the following objectives:

1. Evaluate the performance and carcass quality traits of growing and finishing cattle fed this new type of oat relative to cattle fed barley or corn-based diets;
2. Determine apparent nutrient digestibility parameters for the LLH-HOG oat relative to barley;
3. Compare rumen fermentation parameters (pH; VFA concentrations) in rumen fluid from steers fed the LLH-HOG oat- and barley-based finishing diets; and
4. Establish recommendations for the use of LLH-HOG oat in feedlot diets for cattle.

3.0 PERFORMANCE AND CARCASS CHARACTERSTICS OF GROWING AND FINISHING CATTLE FED A LOW LIGNIN HULL, HIGH OIL GROAT OAT [1]

3.1. Introduction

Commercial cattle production relies on the inclusion of cereal grains to increase the dietary energy concentration of finishing rations. This improves live animal performance and leads to desirable carcass characteristics of grain-finished beef. Although the choice of cereal grain utilized in feedlot diets depends on cost and availability, animal performance must be taken into account when selecting a particular cereal grain. In the United States, corn is the principal feed grain included in feedlot diets due to availability, price and excellent animal performance (Gray and Stallknecht 1988).

In western Canada and in the northwest United States, barley is an important feed grain (Kincheloe et al. 2003). Studies comparing the performance of cattle fed barley or corn generally report that corn is a superior feed grain for cattle, particularly when fed as a steam-flaked product (Owens et al. 1997). However, there are reports of similar animal performance and feeding value for these feed grains (Kincheloe et al. 2003; Beauchemin and Koenig 2005). Oat grain is used to a lesser extent in growing and finishing rations for cattle. In contrast to other cereal grains, oat typically has a higher oil content (5.2%) compared to barley (2.2%) or corn (4.3%), (NRC 1996). However, despite this difference, oat typically has a lower metabolizable energy content (2.78 Mcal ME kg^{-1} DM) relative to corn (3.18) or barley (3.04) (NRC, 1996). This is due to the oat kernel having a higher proportion of hull relative to corn or barley. Approximately 25% of the weight of the oat kernel is hull. Typical oat hulls contain 5.5-6.0% ADL which has a negative association with hull digestibility (Thompson et al. 2000). Lower metabolizable energy content of oat grain has limited its use in feedlot diets primarily to backgrounding programs where animals are not fed for maximum growth rate.

The development of the new oat type at the Crop Development Centre at the University of Saskatchewan has successfully combined the characteristics of a low lignin hull (<1% ADL) and high oil groat (>10% oil) which may result in a significant improvement in its feed value

[1] Manuscript published in the Canadian Journal of Animal Science 2009, vol. 89(4):521-530

relative to other oat varieties and barley, but there has not been any evaluation of the new LLH-HOG oat with growing or finishing cattle.

The objectives of this trial were to evaluate the performance and carcass quality traits of growing and finishing cattle fed this new type of oat relative to cattle fed barley- or corn-based diets.

3.2. Materials and Methods

3.2.1. Animals and Housing

Trial 1

Four hundred commercial crossbred steers (275.4 ± 20.8 kg) supplied by Pound-Maker Agventures, Lanigan, SK were assigned to one of 12 pens (33 or 34 head per pen) and one of two dietary treatments in a completely randomized design to determine the effect of grain source on cattle performance and ultrasound subcutaneous fat (USFAT) and *l. dorsi* area (USLDA) in a 98-day backgrounding study. Cattle were identified by ear tag and vaccinated against infectious bovine rhinotracheitis, parainfluenza 3, bovine viral diarrhea, bovine respiratory syncytial virus (Star Vac®, Novartis Animal Health Canada Inc., Missisauga, ON); *Haemophilus somnus* and *Pasteurella haemolytica* (Somnu-Star Ph®, Novartis Animal Health Canada Inc., Missisauga, ON); clostridial diseases (Covexin® 8, Schering-Plough Animal Health, Schering Canada, Point-Claire, PQ), implanted with Synovex S® (Wyeth Animal Health, Guelph, ON) and treated for parasites (Ivomec®, Merial Canada, Baie D'Urfé, PQ).

At the start and end of the test, steers were weighed on two consecutive days prior to the morning feeding and the average weight was used to determine initial and final weights. Steers were weighed every two weeks during the study and data collected was used to measure the following performance parameters: weight gain, average daily gain (ADG), dry matter intake (DMI), and feed efficiency. Steers were housed outdoors in pens measuring 489 m^2 with an open south-facing shed. Perimeter fencing was 3.3 m high with 20% porosity. Steers had unrestricted access to water at heated, automatic water bowls and feed was delivered to a concrete feedbunk in each pen.

Trial 2

Two hundred and forty commercial crossbred steers (341.7 ± 18.1 kg) were purchased from local auction markets and transported to the Beef Cattle Research Unit near the University of Saskatchewan, Saskatoon, SK. Prior to the start of test, all calves were processed as per the protocol outlined in Trial 1. Steers were assigned to 24 pens (10 head per pen) and one of three dietary treatments in a completely randomized design to determine the effect of grain source on cattle performance, USFAT and USLDA and carcass traits. The finishing phase of the experiment was preceded by a 56-day backgrounding period. Steers were re-implanted with Component TE-S® (Elanco Animal Health, Calgary, AB) at the start of the finishing period. Steers were housed outdoors in pens measuring 286 m^2. Perimeter fencing was 3.3 m high with 20% porosity. Steers had unrestricted access to water at heated, automatic water bowls and feed was delivered to a concrete feedbunk in each pen. Initial, bimonthly (every two weeks) and end of test weights were taken as per Trial 1. The target end-point for slaughter was 650 kg (unshrunk) live weight. Animals used in both experiments were cared for in accordance with the guidelines of the Canadian Council on Animal Care (1993).

3.2.2. Diets and Feeding Protocol

Prior to the start of the performance studies, cattle were fed processed grass hay for three days post-arrival and then switched to a diet consisting of 50% barley silage, 20% grass hay, 5% supplement pellets and 25% barley grain (as fed basis). Forages (barley silage, brome grass hay and barley straw) for Trials 1 and 2 were obtained from the University of Saskatchewan farm. The grass hay and barley straw were processed through a Haybuster Model H-1000 tub grinder (DuraTech Industries International, Inc. Jamestown, ND) using a 7.6- cm screen. The LLH-HOG oat was produced by the Crop Development Centre of the University of Saskatchewan, and the barley and corn were purchased from commercial sources. The barley and oat grain were processed in a Roskamp Model J roller mill (Roskamp Champion, Waterloo, IA). Average particle sizes of the processed barley and oat grains were 2.22 and 2.62 mm and the bulk densities of the processed grains were 52.7 and 44.9 kg hL^{-1}, respectively. The corn was purchased from a local feed company as dry-rolled corn (Roskamp roller mill Roskamp Champion, Waterloo, IA). The average particle size was 1.21 mm and the bulk density was 58.0

kg hL $^{-1}$. Supplement pellets were formulated to supply protein, minerals, vitamins and monensin sodium and manufactured at the University of Saskatchewan feedmill. Cattle were fed twice daily at 0900 and1400 h.

For each trial, orts were removed from the feedbunks on weigh days before feeding, weighed and recorded. Complete mixed diet samples were collected every two weeks by sampling feedbunks immediately following feed delivery. A 2 kg subsample of each diet was frozen at -20°C for subsequent chemical analysis. Samples were thawed and dried in a forced-air oven (55°C) for a minimum of 72 h or until samples reached a constant weight to determine DM content and then composited by month and ground through a Christie & Norris laboratory mill equipped with a 1 mm screen (Christie-Norris Ltd. Chelmsford, UK).

The average composition of the diets fed in Trial 1 is presented in Table 3.1. Both diets were formulated to 12% crude protein and to 1.51 and 0.92 Mcal NEm and NEg kg^{-1} DM, respectively, based on the assumption that the LLH-HOG oat was similar in energy value to barley grain (2.06 and 1.40 Mcal NEm and NEg kg^{-1} DM, respectively; NRC,1996). Target gains of the backgrounding program were 1.15 kg d^{-1} based on NRC (1996). Throughout the trial, the weight of feed delivered to each pen was recorded daily. The actual amount fed was based on the previous day's delivery and a visual assessment of the bunk prior to the morning feeding. Actual dry matter intake was calculated based on dry matter delivered to the bunk less the weight of orts recorded every second week.

In Trial 2, the approach to diet formulation was to include all three cereal grains at equal levels in both the backgrounding and finishing diets in order to compare the performance of the LLH-HOG oat-fed cattle to that of barley- or corn-fed cattle. During the 56-day backgrounding phase of Trial 2, diets consisted of 36.1% barley silage, 54.8% grain and 9.1% supplement (DM basis) (Table 3.2). Respective NE_m and NE_g values were 1.70 and 1.09 Mcal kg^{-1} DM for the oat and barley diets, again assuming equal energy density for the two grains and 1.77 and 1.15 Mcal kg^{-1} DM for the corn-based diet. The finishing diets consisted of 88.2% grain, 6.7% supplement and 5.1% barley silage (Table 3.2) and were formulated to contain a minimum of 12% protein (DM basis).

Table 3.1. Average ingredient and chemical composition of diets fed in Trial 1

	Diet	
	LLH-HOG Oat	Barley
Total mixed diet, % DM		
Barley silage	21.9	21.9
Barley grain, rolled	-	37.8
Oat grain, rolled	37.8	-
Grass hay	29.0	29.0
Barley straw	3.7	3.7
Supplement	7.7	7.7
Supplement, % DM		
Canola meal	63.5	31.7
Barley grain, ground	3.6	34.4
Calcium carbonate	10.1	11.1
Trace mineral salt[z]	5.5	5.5
Vitamin AD premix[y]	8.8	8.8
Vitamin E premix[x]	0.1	0.1
Rumensin® premix[w]	4.9	4.9
Tallow	3.5	3.5
Chemical composition, % DM		
CP	11.7	11.7
EE	5.9	3.0
ADF	27.4	26.2
NDF	43.6	40.3
Ca	0.64	0.62
P	0.31	0.32

[z] Trace mineral salt containing 91.5% NaCl, 120 ppm Se, 12,000 ppm Zn, 10,000 ppm Mn, 4,000 ppm Cu, 200 ppm I and 60 ppm Co.

[y] Premix containing 440,500 IU vitamin A kg^{-1} and 88,000 IU vitamin D_3 kg^{-1}.

[x] Vitamin E premix containing 500,000 IU kg^{-1}.

[w] Rumensin® premix containing 3% monensin sodium.

Feed samples from all trials were analyzed for moisture (AOAC-930.15), ash (AOAC-924.05), CP (AOAC-984.13), EE (AOAC-920.39) and starch (AOAC-996.11). Acid detergent fibre and NDF were analyzed using an ANKOM 200 fibre analyzer (Ankom Technology Corp., Fairport, NY) (ANKOM 1997). Calcium and phosphorus were quantified by Norwest Labs (Lethbridge, AB) according to AOAC method 985.01 using an inductively coupled plasma spectrometer.

Table 3.2. Average ingredient and chemical composition of diets fed in Trial 2

	Backgrounding Diet			Finishing Diet		
	Oat	Barley	Corn	Oat	Barley	Corn
Total mixed diet, % DM						
Barley silage	36.2	36.2	36.2	5.1	5.1	5.1
Barley grain, rolled	-	54.8	-	-	88.2	-
Oat grain, rolled	54.8	-	-	88.2	-	
Corn grain, rolled	-	-	54.8	-	-	88.2
Supplement	9.1	9.1	9.1	6.7	6.7	6.7
Supplement, % DM						
Canola meal	53.8	14.7	54.6	25.7	-	41.7
Barley grain, ground	14.4	52.5	3.1	31.8	55.4	-
Urea	-	-	9.8	-	-	15.5
Calcium carbonate	10.0	11.1	11.0	16.5	18.6	17.3
Trace mineral salt[z]	5.0	5.0	5.0	6.5	6.5	6.5
Vitamin AD premix[y]	8.8	8.8	8.8	9.5	9.5	9.5
Vitamin E premix[x]	0.1	0.1	0.1	0.2	0.2	0.2
Rumensin® premix[w]	4.4	4.4	4.4	6.0	6.0	6.0
Tallow	3.5	3.5	3.5	3.4	3.4	3.4
Chemical composition, % DM						
CP	11.7	12.3	12.9	12.3	12.2	12.5
NDF	35.4	31.5	26.1	24.7	18.0	13.4
ADF	21.9	18.5	17.1	13.3	9.2	6.1
Ca	0.56	0.58	0.84	0.55	0.52	0.53
P	0.37	0.41	0.47	0.36	0.30	0.32
EE	7.0	3.7	3.9	8.0	2.4	4.0

[z] Trace mineral salt containing 91.5% NaCl, 120 ppm Se, 12,000 ppm Zn, 10,000 ppm Mn, 4,000 ppm Cu, 200 ppm I and 60 ppm Co.

[y] Premix containing 440,500 IU vitamin A kg^{-1} and 88,000 IU vitamin D_3 kg^{-1}.

[x] Vitamin E premix containing 500,000 IU kg^{-1};

[w] Rumensin® premix containing 3% monensin sodium.

Net energy for maintenance for treatment diets was calculated based on performance data (animal weights, ADG and DMI) according to Zinn et al. (2002). The retained energy formula for large-framed steer calves (RE = $[0.0493BW^{0.75}]ADG^{1.097}$; NRC, 1984) was used for the backgrounding period, and the formula for large-framed yearlings (RE = $[0.0437BW^{0.75}]ADG^{1.097}$; NRC, 1984) was used for the finishing period. NE_m was converted to NE_g according to Zinn and Shen (1998) using the equation: $NE_g = NE_m * 0.877 - 0.41$).

3.2.3. Ultrasound and Carcass Measurements

For Trials 1 and 2, USFAT and USLDA measurements were taken at the start and end of the backgrounding period and at the end of the finishing period in Trial 2. Ultrasound measurements were obtained using an Aloka 500V realtime ultrasound machine (Hitachi Aloka Medical America Inc., Wallingford, CT). equipped with a 17-cm linear array transducer according to Bergen et al. (1996). In Trial 2, the steers were slaughtered at XL Beef in Moose Jaw, SK. Carcass data collected by Canadian Beef Grading Agency graders included hot carcass weight, *l. dorsi* area, grade fat, lean yield and marbling score. Marbling score was based on a 10-point scale where 1 = very abundant, 7 = small and 10 = devoid. Livers were scored for abscesses based on the Elanco scoring system as adapted by McKinnon et al. (1992). In addition, 39 steers were randomly selected (13 from each treatment group) and slaughtered at Plains Processing, Carman, MB. From these animals, in addition to the above carcass measurements, an 8-bone rib section was removed, vacuum packaged and stored at -20ºC. The 8-bone rib section was thawed, weighed and physically dissected into separable muscle, fat and bone. The fat was further sub-divided into subcutaneous, intermuscular and body cavity depots (McKinnon et al. 1993). A 250-g steak from the *l. dorsi* was removed for determination of fatty acid profile. It was vacuum-packaged and stored at -30ºC.

3.2.4. Fatty Acid Analysis of L. dorsi Muscle and Cereal Grains

Longissimus dorsi samples collected during the rib dissections were thawed overnight at 4ºC and then ground twice in a meat grinder fitted with a 32-mm plate. Lipid extraction from a 15 g sample of lean tissue followed a modified procedure of Bligh and Dyer (1959) as outlined

by Williams et al. (2008). Approximately 10 mg of extracted lipid was methylated according to the procedure outlined by Keough and Kariel (1987). Fatty acid methyl esters (FAME) were identified by gas chromatography (GC) using an Agilent 6890 Series GC system equipped with an Agilent 7683 injector (Agilent Technologies, Wilmington, DE) using a 100 m x 0.25 mm x 0.2 µm fused silica capillary column (SP-2560 Supelco Park, Bellefonte, PA) under the following conditions: injector at 240°C, detector at 250°C, and oven temperature held at 140°C for 5 min., increased at 4°C min^{-1} to 240°C and then held at 240°C for 10 min. Individual FAME were identified by comparing retention times to a known standard (Code 20A Nu-Check Prep. Inc., Elysian, MN). Concentrations were calculated based on an internal standard (nonadecanoic acid at 100 uL (2.5 mg C19:0 mL^{-1} chloroform) per 10 g extracted lipid) and are expressed as the percentage of total fatty acids quantified.

Cereal grains used in the finishing diets were collected throughout the trial and were composited, subsampled and ground through a Retsch ZM-1 grinder (Verder Scientific, Haan, Germany) using a 1mm screen. Fatty acid methyl esters (FAME) were prepared according to the procedure of O'Fallon et al. (2007). Fatty acid methyl esters were identified by gas chromatography (GC) as previously described under the following conditions: injector at 250°C, detector at 260°C, and oven temperature held at 185°C for 15 min., increased at 5°C min^{-1} to 240°C, and then held at 240°C for 19 min. Individual FAME were identified by comparing retention times to a known standard (Supelco 37 Component FAME Mix # 4885-U, Sigma-Aldrich Co. St. Louis, MO). Concentrations were calculated based on an internal standard (C23:0; 0.5 mg mL^{-1} hexane) and expressed as mg g^{-1} of grain (as is basis).

3.2.5. Statistical Analysis

Data from all trials were analyzed as a completely randomized design using the MIXED model procedure of SAS (SAS Institute Inc., Cary, NC) for analysis of variance for performance and carcass data. Diet was the fixed effect and pen was the experimental unit. The degrees of freedom for means was determined using the Kenward-Roger option. Fisher's Least Significant Difference test was used for means comparison. Significance was declared at $P \leq 0.05$. Fatty acid profiles of *l. dorsi* muscle were analyzed as previously described with the exception that the individual animal was the experimental unit. Liver abscess and marbling scores were analyzed

using the GLIMMIX macro (SAS Institute Inc., Cary, NC) with a binomial error structure and logit data transformation.

3.3. Results and Discussion

3.3.1. Chemical Composition of LLH-HOG Oat Grain

The oil content of the LLH-HOG oat (9.3%) used in this study was c.a. 3 to 4 times the EE content of the barley or corn (Table 3.3) and was significantly higher than that of regular oat (5.4% EE DM basis; NRC 1996). The ADL content of this new oat variety was 1.0% (DM basis) which compares to 3% in typical oat varieties (Van Soest, 1994). Based on these characteristics, the hypothesis of this study was that development of a low lignin hull, high oil groat (LLH-HOG) oat would improve its energy content to levels equal to or superior to barley and potentially approach that of corn grain. This hypothesis was tested by comparing the performance of cattle fed this new oat type relative to cattle fed barley or corn grain at equal dietary inclusion levels in both backgrounding (Trial 1 and 2) and finishing (Trial 2) phases of feedlot production.

3.3.2. Diets

Trial 1

As identified in Table 3.1 the LLH-HOG diet was higher in EE (5.9% vs. 3.0%) than the barley diet which reflected the increased oil content in the LLH-HOG oat (Table 3.3). Acid detergent fibre (27.4% vs. 26.2%) and NDF (43.6% vs. 40.3%) content were higher in the oat diet compared to the barley diet, again reflecting the higher fibre content of oat relative to barley (Table 3.3). Crude protein content of both diets met recommended levels for targeted performance (NRC 1996).

Trial 2

As identified in Table 3.2 the backgrounding diets consisted of 54.8% cereal grain, 36.2% barley silage and 9% supplement. The EE content of the LLH-HOG diet was 7.0%,

whereas those of the barley and corn-based diets were 3.7 and 3.9%, respectively. Similar to diets fed in Trial 1, ADF and NDF were greater in the LLH-HOG diet compared to the barley or corn diet. The finishing diets consisted of 88.2% cereal grain, 5.1% barley silage and 6.7% supplement (Table 3.2). The EE content of the LLH-HOG finisher diet was 8.0% whereas that of the barley- and corn-based diets were 2.4% and 4.0%, respectively.

Table 3.3. Chemical composition and fatty acid profile of cereal grains used in Trials 1 and 2

	Cereal Grain		
Parameter (% of DM)	Oat	Barley	Corn
OM	97.4	97.1	98.5
CP	13.2	12.2	8.1
EE	9.3	2.1	3.5
ADF	15.0	5.2	2.1
NDF	30.4	17.7	7.8
Starch	50.9	57.0	72.7
Fatty Acid (% of total FA quantified)			
C16:0	14.6	20.0	14.0
C18:0	1.4	1.1	1.7
C18:1	44.1	15.0	27.2
C18:2n6	37.3	56.4	54.5
C18:3n3	0.2	*nd*[z]	0.5
C20:1	0.9	0.9	*nd*
C20:4	1.1	6.6	2.1
C24:0	0.4	*nd*	*nd*
SFA	16.4	21.1	15.7
MUFA	45.0	15.9	27.2
PUFA	38.6	63.0	57.1
Total FA (mg/g)[y]	63.7	16.7	26.8

[z]*nd* = not detected
[y]as is

3.3.3. Animal Performance

Trial 1

Dry matter intake was lower (P=0.02) for steers consuming the LLH-HOG oat diet compared to the barley-fed cattle (7.49 vs. 7.72 kg d^{-1}) (Table 3.4). The higher fibre content of the LLH-HOG oat diet was unlikely to have influenced DMI as there was little difference in NDF intake when expressed as a % of body weight (0.97 vs. 0.93; DM basis; data not shown). As well, NDF from concentrates is not considered a source of physically effective NDF and would have minimal impact on intake (Mertens 1997). A more likely factor contributing to the reduced DMI is the fat content of the LLH-HOG oat diet.

Addition of fat to ruminant diets has been shown to have variable effects on digestibility of carbohydrates and DMI, with the amount and type of fat supplemented influencing the response (Doreau and Chilliard 1997). Hutchison et al. (2006) reported lower DMI with 4% tallow or poultry fat addition to finishing diets. Similar results were reported by Felton and Kerley (2004) who supplemented a corn/soybean-based diet with whole raw soybean (normal or high oleic acid content) or choice white grease at 7.5% added fat. In contrast, Zinn (1989) did not find any negative effects of adding 4% or 8% yellow grease to barley-based diets fed to finishing cattle. However, weight gain, feed conversion and NE content of the diet were improved by fat addition. Doreau and Chilliard (1997) stated that addition of up to 5% added fat to ruminant diets will have minimal effects on feed intake and digestibility. In the current study, the LLH-HOG oat diet contained 5.9% EE and this level may have contributed to the lower DMI for steers fed this diet.

Cattle fed the LLH-HOG oat diet had similar ADG compared to the barley-fed cattle (1.28 vs. 1.23 kg d^{-1}) (P=0.12) and slightly exceeded the target rate of 1.15 kg d^{-1} (Table 3.4). As a result, the efficiency of gain (gain:feed) of the oat-fed cattle was improved (P<0.01) by 7.5% (0.171 vs. 0.159). Similar improvements in feed efficiency as a result of fat addition were reported by Zinn (1989); Hutchison et al. (2006); and Felton and Kerley (2004). Improved feed efficiency, particularly as a result of lower DMI and similar ADG reduces the cost of gain in feedlots and can have a marked impact on profitability of feeding cattle. In the case of fat addition, the displacement of dietary carbohydrate by lipid higher in ME is responsible for the improvement in feed efficiency (Andrae et al. 2000).

Table 3.4. Effect of grain source on performance and ultrasound fat and muscle measurement of steers in Trial 1

	Diet			
Parameter	LLH-HOG	Barley	SEM	*P* value
Liveweight (kg)				
Initial	275.4	275.4	0.21	1.00
Final	400.8	395.6	2.21	0.13
DMI (kg/d)	7.49*b*	7.72*a*	0.06	0.02
ADG (kg/d)	1.28	1.23	0.02	0.12
Gain:Feed	0.171*a*	0.159*b*	0.002	<0.01
Ultrasound subcutaneous fat (mm)				
Initial	1.52	1.52	0.04	1.00
Final	2.75	2.72	0.13	0.86
Ultrasound l. dorsi area (cm^2)				
Initial	51.64	51.61	0.32	0.94
Final	65.43*a*	63.81*b*	0.46	0.03
Calculated Energy Density (Mcal kg^{-1})[z]				
NE_m	1.80	1.71	-	-
NE_g	1.17	1.09	-	-

[z] Calculated according to Zinn et al. (2002)
a,b Means followed by a different letter are significantly different ($P \leq 0.05$).

As determined through animal performance, the improved feed efficiency was reflected in 4.9% and 6.9 % higher calculated NE_m and NE_g values of the LLH-HOG oat diet (Table 3.4).

Results of Trial 1, in particular the superior efficiency of gain and the higher dietary NE_m and NE_g content based on animal performance of the LLH-HOG oat-fed cattle, would indicate

that this new oat type is equal to or superior to barley as an energy source in backgrounding diets.

Trial 2

Similar to results observed in Trial 1, lower DMI was observed in steers fed the LLH-HOG diet ($P<0.01$) resulting in improved ($P<0.01$) feed efficiency relative to barley- and corn-fed cattle during the backgrounding period (Table 3.5). No difference in DMI was observed between barley- and corn-fed cattle during this phase of the trial. For the remainder of the finishing period, DMI of the oat-fed cattle was the lowest ($P<0.01$) of the three dietary treatments, as these cattle consumed 1.28 and 2.0 kg d^{-1} less total dry matter than did the barley- and corn-fed cattle, respectively. As discussed for Trial 1, the negative effect of the LLH-HOG oat diet on DMI can be attributed to both the amount and type of fat in the diet.

During the finishing phase of the trial, the cattle consuming the oat-based diet consumed 8.43 kg d^{-1} of the LLH-HOG oat which consisted of 63.7 mg g^{-1} of fatty acids (Table 3.3). Average fatty acid intake from the oat grain was 0.54 kg d^{-1} which based on the fatty acid profile of the oat included, 0.08, 0.24 and 0.20 kg d^{-1} of C16:0, C18:1 and C18:2*n6*, respectively. Total daily fatty acid intakes were 0.16 kg d^{-1} for the barley-fed cattle and 0.27 kg d^{-1} for corn-fed cattle resulting in fatty acid intakes (kg d^{-1}) of 0.03 and 0.04 for C16:0, 0.02 and 0.07 for C18:1, and 0.09 and 0.15 for C18:2*n6*. Based on these three fatty acids which comprise the majority of the fatty acids in the three cereal grains, the ratios of unsaturated to saturated fat consumed were 5.7:1, 3.8:1 and 5.7:1 for the oat, barley and corn-fed cattle, respectively. While it is generally held that carbohydrate digestion, particularly that of fibre, is negatively influenced by supplemental sources of long chain unsaturated fatty acids (Doreau and Chilliard 1997), it is difficult to attribute the reduction in DMI of the cattle fed the LLH-HOG oat-based finishing ration to reduced fibre digestibility as the diet contained only 5.1% barley silage (DM basis). An alternative explanation is that the reduced DMI of the LLH-HOG oat-fed cattle may have resulted from metabolic regulation of feed intake.

Table 3.5. Effect of grain source on performance and ultrasound live fat and muscle measurements of steers in Trial 2

	Diet				
Parameter	Oat	Barley	Corn	SEM	*P* value
Liveweight (kg)					
Initial	341.2	341.8	342.0	0.41	0.35
Day 56	432.4*b*	437.3*a*	437.3*a*	1.38	0.03
Final	623.3*b*	644.8*a*	647.7*a*	3.17	<0.01
Dry matter intake (kg/d)					
Day 1-56	8.22*b*	9.06*a*	9.33*a*	0.10	<0.01
Day 56-EOT	9.56*c*	10.84*b*	11.56*a*	0.13	<0.01
Average daily gain (kg)					
Day 1-56	1.63*b*	1.71*a*	1.70*a*	0.02	0.05
Day 56-EOT	1.40*c*	1.69*b*	1.84*a*	0.03	<0.01
Gain:feed					
Day 1-56	0.198*a*	0.188*b*	0.183*b*	0.003	<0.01
Day 56-EOT	0.147*b*	0.156*a*	0.159*a*	0.002	<0.01
Days on feed	192*a*	179*b*	171*c*	1.36	<0.01
Ultrasound subcutaneous fat (mm)					
Initial	2.8	2.7	2.4	0.18	0.35
Day 56	4.2*b*	4.6*a*	3.8*b*	0.16	0.01
EOT	8.5*b*	8.8*b*	10.0*a*	0.37	0.02
Ultrasound l. dorsi area (cm^2)					
Initial	63.6	61.5	62.9	0.91	0.30
Day 56	72.6*a*	70.7*b*	73.8*a*	0.62	<0.01
EOT	91.2*b*	96.6*a*	98.1*a*	0.89	<0.01
Calculated Energy Density Day 1 to 56 (Mcal kg^{-1} DM[z])					
NE_m	2.07	1.97	1.92	-	-
NE_g	1.40	1.32	1.27	-	-
Calculated Energy Density Day 57 to Slaughter (Mcal kg^{-1} DM[z])					
NE_m	1.92	1.94	1.93	-	-
NE_g	1.28	1.30	1.29	-	-

[z] Calculated according to Zinn et al. (2002).
a,b,c Means followed by a different letter are significantly different ($P \leq 0.05$).

It is recognized that central control centres in the hypothalamus play a role in coordinating signals from perpetual tissues and in regulating intake. Choi and Palmquist (1996) stated that lipid metabolites in the circulation could serve as satiety signals when cows consume excessive amounts of dietary fat. To this end, these workers demonstrated that plasma cholecystokinin levels increased linearly with increased dietary fat levels as DMI decreased.

More recently, Relling and Reynolds (2007) found that feeding rumen inert fat that varied in the degree of unsaturation increased plasma concentrations of several gut peptides including cholecystokinin and glucose-like peptide 1, while DMI was reduced relative to control fed cows. Most interestingly from the point of view of the current study was that the effects were greater for diets supplemented with unsaturated fat relative to saturated fat sources, and for cholecystokinin was greatest for the diet supplemented with a MUFA source. It is possible that rumen escape and absorption of MUFA (e.g. C18:1) and PUFA (e.g. 18:2*n6*) fatty acids may have contributed to metabolic regulation of feed intake of cattle fed the LLH-HOG oat diet, resulting in the observed reduction in DMI.

It is also possible that the oat-fed cattle were experiencing SARA. Herrera-Saldena et al. (1990) observed that 28.0% of oat starch was degraded following a 60-min. *in vitro* incubation compared to 8.8% and 6.4% for barley and corn, respectively. Starch degradation rates of the LLH-HOG oat have been shown to be similar to those of regular oat varieties(CDC Dancer and Derby) (Yu and Niu, 2009). Rapid starch degradation, particularly with high grain rations, can induce SARA, resulting in variable and reduced DMI (Williams et al. 2008).

Performance of the oat-fed cattle during finishing was reduced relative to either the barley- or corn-fed cattle (Table 3.5), including lower ($P<0.01$) ADG, poorer ($P<0.01$) gain:feed, and reduced ($P<0.01$) USLDA at the end of the test. The poor performance of the oat-fed cattle led to the decision to slaughter any cattle that were on feed for greater than 210 days. All corn-fed and all but six barley-fed cattle had been slaughtered by this end-point. Despite this cut-off date, the oat-fed cattle exhibited greater ($P<0.01$) days on feed than the other 2 groups of cattle. Calculated NE_m and NE_g values for the three treatment diets based on animal performance were similar (NE_m, average 1.93 $\pm$ 0.01;NE_g,average 1.29 $\pm$ 0.01). This indicates that the poor performance of steers fed LLH-HOG oat diet can be attributed to reduced DMI and not to the fact that the oat grain was less energy dense than either the barley or corn. These results reflect those of Andrae et al. (2000) who reported that in order for rate of gain to increase with increasing dietary energy density, voluntary feed intake must not decrease.

Over the finishing period, cattle fed corn consumed more feed ($P<0.01$), gained faster ($P<0.01$) and more efficiently ($P<0.01$) and spent less time ($P<0.01$) on feed than barley-fed cattle. Although not all studies comparing these cereal grains show superior performance for corn-fed cattle (Gray and Stallknecht 1988; Kincheloe et al. 2003; Beauchemin and Koenig

2005), the results of the present study are not surprising considering NRC (1996) assigns a higher net energy value of corn grain than either barley or oat.

3.3.4. Ultrasound Measurements

Trial 1

The goal of backgrounding is to promote muscle deposition while minimizing that of fat (Vaage et al. 1998; Block et al. 2001). Table 3.4 shows that during this trial, the change in USFAT was minimal (1.2 mm) with no difference (P=0.86) between treatments. As per the goal of the feeding program, USLDA increased by 13.8 cm^2 for the LLH-HOG oat-fed steers and 12.2 cm^2 for the barley-fed steers. End of backgrounding USLDA was greater (P=0.03) for steers fed the LLH-HOG backgrounding diet, although the absolute difference (1.6 cm^2) was not large. Other researchers have noted similar levels of gain for USLDA and USFAT for cattle in backgrounding programs targeted to similar rates of gain (Block et al. 2001).

Trial 2

Live animal ultrasound measurements are presented in Table 3.5. Live animal ultrasound measurements of carcass backfat and *l. dorsi* area over the entire experiment corroborate results observed for animal performance parameters and indicate slower rates of muscle and adipose tissue accretion for steers consuming the LLH-HOG oat diet. By the end of this study, steers consuming LLH-HOG had a smaller (P<0.01) USLDA measurement than barley- or corn-fed cattle. Final USFAT measurement of oat-fed cattle identified less backfat (P=0.02) than corn-fed cattle, but no significant difference from barley-fed cattle.

3.3.5. Carcass Measurements and Fatty Acid Profile

As indicated in Table 3.6, carcass traits reflected live animal performance. Carcass weight and dressing percentage were lower (P<0.01) for steers fed the LLH-HOG oat-based diet compared to the barley- and corn-based diets, despite longer days on feed for the oat-based diet.

Table 3.6. Effect of grain source on carcass characteristics from steers in Trial 2

	Diet				
Parameter	Oat	Barley	Corn	SEM	*P* value
Carcass weight (kg)	353.4*b*	373.5*a*	378.1*a*	2.40	<0.01
Dressing (%)	58.3*b*	59.7*a*	60.1*a*	0.17	<0.01
Grade fat (mm)	7.7*b*	7.8*b*	9.2*a*	0.43	0.04
L. dorsi (cm^2)	95.6*b*	101.8*a*	100.5*a*	1.03	<0.01
Lean yield (%)	61.4*a*	61.5*a*	60.5*b*	0.32	0.05
Marbling score (% of cattle)					
AAA	17.5	25.0	23.1	4.6	0.51
AA	75.0	70.0	70.5	5.0	0.75
A	7.5	1.3	1.3	2.0	0.11
Rib composition (%)					
Bone	11.4	11.6	11.1	0.51	0.82
Lean meat	61.0	60.8	60.4	1.06	0.92
Fat	27.6	27.7	28.5	1.07	0.80
Rib fat distribution (% total fat)					
Subcutaneous fat	36.6	33.6	33.5	1.18	0.13
Body cavity fat	5.8	6.1	5.6	0.30	0.50
Intermuscular	57.6	60.4	61.0	1.04	0.08
Liver abscess score (% of cattle)					
0	43.8	55.0	59.0	5.6	0.16
1	15.0	10.0	11.5	3.7	0.62
2	5.0	3.7	5.1	2.3	0.90
3	36.3	31.2	24.4	5.2	0.29

[z] Liver abscess score: 0=no abscess; 1=one small abscess; 2=two to four small to medium (<2.54 mm) abscesses; 3=one or more large (>2.54 mm) abscesses or greater than four small to medium abscesses.

a,b Means followed by a different letter are significantly different ($P \leq 0.05$).

Steers finished on the LLH-HOG oat diet had a smaller ($P<0.01$) *l. dorsi* area and reduced grade fat($P=0.04$), despite the fact that these cattle spent 13 and 21 days longer on feed than the barley- and corn-fed cattle, respectively.Carcasses of barley-fed cattle were similar to corn-fed cattle with the exception that corn-fed cattle had more ($P=0.04$) grade fat and lower ($P=0.05$) lean meat yield. This reflects the higher energy content of corn and the fact that the barley- and corn-fed cattle were killed at a similar live weight. Marbling scores were slightly higher for the oat-

fed cattle indicating poorer marbling. No differences in rib composition were noted between treatments, although there was a trend (P=0.08) to higher intermuscular fat content in barley- and corn-fed cattle.

The fatty acid profile and fat content of *l. dorsi* samples is presented in Table 3.7. The extracted intramuscular fat content of the corn-fed cattle was greater (P=0.04) than that of either the oat-or barley-fed cattle. The fatty acids analyzed are the primary fatty acids making up ruminant adipose tissue. The intent was to determine if feeding the high oil oat would influence the relative composition of fatty acids in muscle tissue. No attempt was made to identify and quantify conjugated linoleic acid (CLA) or its isomers as these cattle were finished on high grain diets. It has been shown that cattle on such feeding regimes exhibit very low CLA levels in muscle tissue (Mir et al. 2003). The saturated fatty acids present in greatest amounts were C14:0, C16:0 and C18:0 (Table 3.7) which is typical of beef adipose tissue (Rhee 2000). Palmitic acid was higher (P<0.01) in barley-fed cattle, while C18:0 was higher in the oat-fed cattle with no difference between treatments for C18:1. Differences in C16:0 between barley and the oat and corn treatments may reflect differences in the original grain (Table 3.3). Lack of a treatment effect on C18:1 content of the *l. dorsi* of oat-fed cattle is somewhat surprising as the oat grain contained more C18:1 than corn, which contained higher levels than the barley grain (Table 3.3).

As reviewed by Jenkins (1993), rumen biohydrogenation of dietary fatty acids has a major influence on the fatty acid composition of ruminant adipose tissue. The higher level of C18:0 in the *l. dorsi* of the oat-fed cattle likely reflects the greater C18:1 intake of the oat-fed cattle and the resulting ruminal biohydrogenation of this fatty acid to C18:0. Linoleic acid (C18:2*n6*) was higher (P<0.01) in oat and corn-fed cattle and likely reflects rumen escape of dietary C18:2*n6*. Again, while barley grain exhibited a higher C18:2*n6* level as a percentage of total fatty acids, dietary intake during finishing of C18:2*n6* was greater for the oat-fed (0.2 kg d^{-1}) and corn-fed (0.15 kg d^{-1}) than for the barley-fed cattle (0.09 kg d^{-1}).

As stated by Andrae et al. (2001) an increased intestinal supply of C18:2*n6* can result from decreased ruminal biohydrogenation or increased dietary supply of unsaturated fat. Both factors may have contributed to the higher C18:2*n6* levels found in the oat and corn-fed cattle in this study. Corn-fed cattle had the lowest (P<0.01) level of C18:3*n3* and C20:4, although actual differences were small (Table 3.7). As a result of these differences in individual fatty acid concentrations, total PUFA as a portion of total fatty acids was greater (P<0.01) for both the oat

and corn-fed cattle, while the oat-fed cattle had lower (*P*=0.01) levels of MUFA, with no difference between treatments for the proportion of SFA. These changes explain the higher (*P*=0.01) PUFA:SFA ratio found in intramuscular fat of the oat and corn-fed cattle.

Table 3.7. Effect of diet on fatty acid profile of *longissimus dorsi* muscle

	Diet				
FA (mg 100^{-1} mg total FA)	Oat	Barley	Corn	SEM	*P* value
14:0	3.09	3.24	3.43	0.16	0.34
14:1	0.51	0.74	0.69	0.07	0.08
16:0	26.35*b*	29.34*a*	27.60*b*	0.51	<0.01
16:1	3.16*b*	4.63*a*	4.14*a*	0.28	<0.01
17:0	1.13*b*	1.*32ab*	1.51*a*	0.08	0.01
18:0	17.83*a*	13.41*b*	13.59*b*	0.51	<0.01
18:1[z]	40.28	42.28	41.66	0.74	0.16
18:2	6.77*a*	4.36*b*	6.12*a*	0.36	<0.01
18:3	0.40*a*	0.47*a*	0.33*b*	0.02	<0.01
20:4	1.32*a*	1.01*ab*	0.91*b*	0.11	0.03
PUFA	8.49*a*	5.83*b*	7.36*a*	0.47	<0.01
MUFA	43.95*b*	47.65*a*	46.48*a*	0.79	0.01
SFA	48.40	47.30	46.13	0.70	0.09
PUFA:SFA	0.17*a*	0.12*b*	0.16*a*	0.01	0.01
% Fat	3.06*b*	3.11*b*	3.99*a*	0.28	0.04

a,b Means followed by a different letter are significantly different (*P*≤0.05).

[z]C18:1, both cis and trans co-eluted.

3.4. Conclusion

The results of this study indicate that an oat type developed on the basis of a low acid-detergent lignin hull and high oil groat combination has significant potential for use in backgrounding programs. Relative to cattle backgrounded on barley grain (Trials 1 and 2) or

corn (Trial 2), DMI was reduced, ADG was similar (Trial 1) or slightly reduced (Trial 2), and feed efficiency was superior for the LLH-HOG oat-fed cattle. Cattle fed the LLH-HOG oat grain finishing diet exhibited a marked reduction in DMI. This resulted in reduced ADG, poorer gain to feed ratio, longer days on feed, failure to achieve targeted slaughter weights and lower dressing percentage and carcass weights. No differences were observed in rib composition, although cattle fed either the oat and corn diets had a greater proportion of unsaturated to saturated fatty acids than barley-fed cattle. Further research is required to identify factors limiting feed intake of cattle fed the LLH-HOG oat type at concentrated levels in finishing diets.

4.0 COMPARISON OF NUTRIENT DIGESTIBILITY AND RUMEN FERMENTATION CHARACTERISTICS OF STEERS FED A LOW LIGNIN HULL, HIGH OIL GROAT OAT AND BARLEY

4.1. Introduction

The backgrounding performance studies described in Chapter 3 provide preliminary evidence that the energy value of the low lignin hull, high oil groat (LLH-HOG) oat is similar or superior to barley. This supports the work of Fuhr (2006) who conducted a digestibility study using lactating dairy cows to evaluate the prototype of the new oat variety. His research indicated that the DE value of the LLH-HOG oat relative to barley was 3.55 versus 3.58 Mcal kg^{-1} DM, respectively. There have been no studies evaluating nutrient utilization of the new oat variety in feedlot diets for beef cattle. Since the economic value of a cereal grain in feedlot diets is predominately determined by its digestible energy content, it is important to determine the energy content of the new LLH-HOG oat relative to barley.

Finishing diets contain a high proportion of cereal grains that increase the supply of readily fermentable carbohydrates such as starch. Increasing the supply of fermentable carbohydrate stimulates the growth rates of rumen microbes, which increases the rate of fermentation end-product production (Nagaraja and Titgemeyer 2007). As both the rate and extent of ruminal fermentation of energy-yielding carbohydrates such as starch vary among grain sources, it also is important to assess the rumen fermentation characteristics of the LLH-HOG oat in comparison to a commonly used feed grain such as barley.

Results from the feedlot finishing trial described in Chapter 3 indicated that steers fed diets containing a high proportion of the LLH-HOG oat had lower DMI and reduced animal performance compared to steers fed barley- or corn-based finishing diets. It is possible that the rate and extent of rumen fermentation of LLH-HOG oat was higher than the barley or corn and may have increased the incidence of rumen acidosis in these cattle. Ruminal pH is determined by the relative concentrations of bases, acids and buffers, and a ruminal pH measurement of 5.6 is often used as a benchmark to indicate a metabolic disorder known as chronic or sub-acute ruminal acidosis (SARA) (Owens et al. 1998). More recently, Penner et al. (2007) indicated that ruminal acidosis (RA) occurred when ruminal pH was <5.8. These workers further categorized

RA into the following categories: 1) mild RA (5.8 > ruminal pH > 5.5), 2) moderate RA (5.5 > ruminal pH > 5.2), and 3) acute RA (ruminal pH < 5.2). Detailed rumen metabolism studies may assist in better understanding rumen fermentation characteristics of the LLH-HOG oat and identify factors that may have contributed to the reduction in DMI observed in steers fed LLH-HOG oat-based finishing diets as described in the previous chapter.

The objectives of this trial were to:

1. determine apparent nutrient digestibility parameters for the LLH-HOG oat relative to barley; and
2. compare rumen fermentation parameters (pH; VFA concentrations) in rumen fluid from steers fed the LLH-HOG oat- and barley-based finishing diets.

4.2. Materials and Methods

4.2.1. Animals and Housing

Trial 1

Twenty crossbred yearling steers (355.5 ± 24.7 kg) were transported from the Beef Cattle Research Unit of the University of Saskatchewan (Saskatoon, SK) to the Livestock Research Barn in early September 2004 for use in a feed intake and total tract nutrient digestibility study. Steers were housed individually in 9.6 m^2 pens with rubber floor mats and individual water bowls. The trial was conducted over two 25-day periods in a randomized complete block design.

Trial 2

Four crossbred yearling steers, surgically fitted with plastic ruminal cannulae having a 10-cm diameter opening (Bar Diamond Inc., Parma ID) were housed individually in pens as described in Trial 1 in the Livestock Research Barn at the University of Saskatchewan for use in a rumen metabolism study. The trial was conducted over two periods. Steers were transitioned and adapted to their finishing diets for a 21-day period followed by a 24-hour period where rumen contents were collected every 2-hour beginning at 0800 h. Rumen fluid samples were collected for a second time seven days following the first collection in each period.

Animals in both trials were cared for in accordance with the guidelines of the Canadian Council for Animal Care (1993).

4.2.2. Dietary Treatments and Feeding Protocol

Trial 1

Barley silage (AC Rosser) was obtained from the University of Saskatchewan dairy unit. The barley grain was obtained from commercial sources through the Beef Cattle Research Unit. The LLH-HOG oat was obtained as described in Chapter 3. Prior to processing, the bulk density of the barley was 62.0 kg hL^{-1} and the bulk density of the LLH-HOG oat was 49.7 kg hL^{-1}. The barley and LLH-HOG oat were processed in a Roskamp Model J roller mill (Roskamp Champion, Waterloo, IA) at the University of Saskatchewan feedmill and transported to hopper bottom storage bins located adjacent to the Livestock Research Barn. The bulk densities of the processed grains were 52.7 kg hL^{-1} and 44.9 kg hL^{-1}, respectively.

The digestibility study included seven treatments. The control diet consisted of 100% barley silage. Treatments 2 through 4 included 28, 56 and 84% rolled barley grain (DM basis). Treatments 5 through 7 included 28, 56 and 84% rolled LLH-HOG oat. In each period, two steers were randomly assigned to the control diet and three steers were randomly assigned to each treatment diet. Steers were fed each day at 0730 and 1530 h. Feed was offered *ad libitum* during the adaptation and voluntary intake periods and restricted to 90% of voluntary intake during the restricted intake and collection period. Chromic oxide pellets (6.06% Cr_2O_3, DM basis) were fed during the restricted intake and collection periods at a rate of 400 g per day (as-fed basis), split between the a.m. and p.m. feedings. All steers were fed 25 g of trace mineralized salt during the morning feeding (Co-op® High Selenium T.M. Salt (for cattle), Federated Co-operatives Ltd. Saskatoon, SK) containing 91.5% sodium chloride, 120 ppm added selenium, 12,000 ppm zinc, 10,000 ppm manganese, 4,000 ppm copper, 200 ppm iodine, and 60 ppm cobalt. Fifty grams of a vitamin premix containing 1,000,000 IU vitamin A kg^{-1}, 100,000 IU vitamin D3 kg^{-1} and 1,000 IU vitamin E kg^{-1} was fed to each steer during the morning feeding. This premix was made by mixing 0.1 kg Co-op® Vitamin ADE Premix (for livestock) (Federated Co-operatives Ltd., Saskatoon, SK) with 9.9 kg of ground barley.

Orts were removed from the feedbunks prior to the morning feeding. The weight of orts collected was subtracted from the amount of feed provided to each steer the previous day to determine daily feed intake. During the collection period, orts were retained for dry matter

determination and subsequent determination of chromic oxide content. During the collection period, samples of each complete mixed diet were obtained and frozen at -20ºC for subsequent dry matter determination and chemical analysis. The ingredient makeup and chemical composition of the diets fed in Trial 1 is presented in Table 4.1.The chemical composition of the LLH-HOG oat, barley and barley silage fed in Trial 1 is presented in Table 4.2.

Trial 2

Barley silage (AC Rosser) was obtained from the University of Saskatchewan dairy unit. The barley was obtained from commercial sources through the Beef Cattle Research Unit. The LLH-HOG was obtained as described in Chapter 3. The barley and LLH-HOG oat were processed in a Roskamp Model J roller mill (Roskamp Champion, Waterloo, IA) at the University of Saskatchewan feedmill and transported to the Livestock Research Barn and stored in mini-tote bags. Supplement pellets used in the feedlot finishing study described in Chapter 3 were manufactured at the feedmill at the Beef Cattle Research Unit and transported to the Livestock Research Barn in mini-tote bags.

During the metabolism study, each steer was randomly assigned to one of two finishing diets (LLH-HOG oat- or barley-based diet) fed during the finishing cattle trial described in Chapter 3. Finishing diets consisted of 88.2% rolled LLH-HOG oat or barley, 5.1% barley silage and 6.7% supplement pellets (DM basis).

Table 4.1. Ingredient and nutrient composition of diets fed in digestibility study

				Ingredient makeup of TMR (%DM)			
LLH-HOG Oat	0	28	56	84	0	0	0
Barley	0	0	0	0	28	56	84
Barley Silage	100	72	44	16	72	44	16
				Nutrient Composition (%DM)			
DM	30.1±1.1	37.7±0.1	49.3±0.8	70.4±0.2	37.9±0.8	49.8±0.5	71.6±0.2
OM	90.7±0.7	92.1±0.2	93.1±0.0	94.5±0.2	92.6±0.1	94.1±0.1	95.8±0.0
CP	12.4±0.6	13.3±0.5	14.1±0.1	14.7±0.4	12.6±0.3	12.6±0.1	12.8±0.1
EE	3.6±0.5	4.9±0.3	6.6±0.2	7.7±0.1	3.1±0.3	2.9±0.0	2.3±0.1
ADF	33.6±0.5	27.8±0.3	22.7±0.7	17.8±0.6	25.1±0.3	18.0±0.3	11.0±0.2
NDF	51.0±0.0	43.8±0.3	38.3±0.7	33.0±0.2	40.4±0.9	31.7±0.9	21.9±0.6
GE (kcal/kg)	4442.5±65.8	4509±18.4	4584±5.7	4668±29.7	4414.5±38.9	4402±18.4	4407.5±2.1

Table 4.2. Chemical composition of cereal grains and silage used in the digestibility study

Chemical Composition	LLH-HOG Oat	Barley	Barley Silage
DM%	90.6	89.4	30.1
OM%	96.0	97.0	90.7
CP%	17.0	12.8	12.4
EE%	9.3	2.1	3.6
ADF%	15.1	5.1	33.6
NDF%	30.2	17.6	51.0

At the conclusion of period 1, each steer was gradually adjusted to the opposite finishing diet by substituting 25% of the LLH-HOG oat or barley with the other grain every fourth day during the 21-day period prior to collection for period two. This provided a minimum of five days on the final diet to fully adjust prior to the second collection. Steers were fed each day at 0730 and 1530 h. Feed was offered ad libitum throughout the trial. Orts were removed from the feedbunks prior to the morning feeding. During the collection period, samples of each complete mixed diet were obtained and frozen at -20º C for subsequent dry matter determination and chemical analysis. The ingredient makeup and chemical composition of the diets fed in Trial 2 is presented in Table 4.3.

4.2.3. Data Collection and Analysis

Trial 1

Diet samples and orts were thawed and subsequently dried in a forced-air oven (55°C) for a minimum of 72 hours or until samples reached a constant weight to determine DM content. Following drying, diet samples were composited by treatment and orts by animal and ground through a Christie & Norris laboratory mill equipped with a 1-mm screen (Christie-Norris Ltd. Chelmsford, UK). Samples were thoroughly mixed, sub-sampled and representative samples transferred to 40-dram laboratory vials for analysis.

Table 4.3. Ingredient makeup and chemical composition of diets fed in metabolism study

	Diet	
	LLH-HOG Oat	Barley
Total mixed diet, % DM		
Barley silage	5.1	5.1
Barley grain, rolled	-	88.2
Oat grain, rolled	88.2	-
Supplement	6.7	6.7
Supplement, % DM		
Canola meal	25.7	-
Barley grain, ground	31.8	55.4
Urea	-	-
Calcium carbonate	16.5	18.6
Trace mineral salt[z]	6.5	6.5
Vitamin AD premix[y]	9.5	9.5
Vitamin E premix[x]	0.2	0.2
Rumensin® premix[w]	6.0	6.0
Tallow	3.4	3.4
Chemical composition(DM)		
OM%	95.4	96.0
CP%	13.0	12.6
ADF%	12.2	7.5
EE%	9.2	2.8
GE kcal/kg	4691	4374

[z]Trace mineral salt containing 91.5% NaCl, 120 ppm Se, 12,000 ppm Zn, 10,000 ppm Mn, 4,000 ppm Cu, 200 ppm I and 60 ppm Co.
[y]Premix containing 440,500 IU vitamin A kg^{-1} and 88,000 IU vitamin D_3 kg^{-1}
[x]Vitamin E premix containing 500,000 IU kg^{-1};
[w]Rumensin® premix containing 3% monensin sodium.

During the collection period 500 ± 100 g of feces were collected at 0800, 1500 and 2200 h. Fecal samples from each steer were composited at the end of each day and a 500 g sub-sample was frozen at –20ºC for subsequent analysis. Following removal from storage, fecal sub-samples were dried in a forced-air oven at 55°C for a minimum of five days or until constant weight was obtained. Fecal samples were composited by steer and ground through a Christie & Norris laboratory mill equipped with a 1-mm screen. A representative sample of chromic oxide pellets fed during each period was ground through a 1.0 mm screen using a Retsch ZM-100 grinder(Verder Scientific, Haan, Germany). Ground feed, fecal and chromic oxide pellet samples

were thoroughly mixed and representative samples were transferred to 40-dram laboratory vials and stored for analysis.

Feed and fecal samples were analyzed for moisture (AOAC-930.15), ash (AOAC-924.05), CP (AOAC-984.13) and EE (AOAC-920.39). Gross energy (GE) was determined in a Parr 1281 oxygen bomb calorimeter (Parr Instrument Co., Moline, IL). Acid detergent fibre and NDF were analyzed using an ANKOM 200 fibre analyzer (Ankom Technology Corp., Fairport, NY) according to the methods of Van Soest et al. (1991). The NDF procedure included α-amylase and sodium sulfite as per the procedure of Van Soest et al. (1991). Chromic oxide pellets and fecal samples were analyzed for chromic oxide as described by Fenton and Fenton (1979). Chromium in ort samples was determined by atomic absorption following the mineral digestion procedure of Zasoski and Burau (1977).

Apparent nutrient digestion coefficients were calculated using the indicator method described by Schneider and Flatt (1975). Digestible energy was calculated by multiplying GE in feed by the apparent GE coefficient for each steer and is reported as kcal kg^{-1}.

4.2.4. Rumen Fluid Collection and Rumen pH Measurements (Trial 2)

Rumen fluid samples were collected from each steer every two hours over a 24-hour period, beginning at 0800 to measure pH and analyze rumen contents for total volatile fatty acid (VFA) concentration and the relative proportion of individual short chain fatty acids. Animals were fed immediately after samples were collected at 0800 and 1600 h. Representative samples of rumen contents were obtained by collecting samples from four separate locations in the rumen (rumen mat, reticulum, dorsal sac and ventral sac). Samples collected from each location were strained through four layers of cheesecloth and approximately 50 mL of filtrate from each sample was composited for each animal at each collection time. Rumen pH measurements were taken in duplicate with a Model 265A portable pH meter (Orion Research Inc., Beverly, MA) immediately after the composite sample was prepared. The pH value of the rumen fluid sample was the mean of duplicate measurements. Following pH measurement, a 5-mL aliquot of filtrate was preserved by adding 1 mL of 25% (wt/vol) metaphosphoric acid (HPO_3) for determination of VFA concentration. Samples were stored at -20°C until analysis.

4.2.5. Volatile Fatty Acid Analysis of Rumen Fluid

Rumen fluid samples were removed from frozen storage and thawed overnight in a refrigerator at 3ºC. Thawed samples were thoroughly mixed by vortexing for 5 to 10 seconds. Samples were then centrifuged at 11,600 rpm at 4ºC for 15 minutes. (Model J6-MC Beckman Coulter™, Palo Alto, CA). Subsequently, 120 µl of supernatant was transferred to duplicate 1.5-ml micro tubes with snap caps. To each sample, 50 µL of trimethyl acetic acid (TMA) in methanol (TMA: 97.91 mM) was added to each microcentrifuge tube as an internal standard followed by addition of 880 µL of acetonitrile (ACN) (99.9% v/v). The closed tubes were then vortexed for 5 seconds prior to centrifuging at 4,200 rpm for five minutes in a microcentrifuge (Model 17 Beckman Coulter™, Palo Alto, CA). Supernatant was transferred into a clean, labeled screw-top GC vial using a 14.6-cm glass pipet. Screw caps were securely fastened and the GC vials were placed on the autosampler. A standard curve was prepared using VFA standard 46975-U (Nu-Chek Prep Inc., Elysian, MN) to establish the standard curve. This standard consisted of 10mM of each VFA (acetic, propionic, butyric, n-valeric, n-caproic, formic, iso-butyric, iso-valeric, iso-caproic and heptanoic acid) in deionized water.

Samples were injected (0.5 µL) via an Agilent 7683 Series injector (Wilmington, DE) into an Agilent 6890 Series GC System (Wilmington, DE) fitted with a 30.0 m x 320 µm x 0.25 µm Zebron ZB-FFAP GC capillary column (Phenomenex Inc., Torrance, CA) under the following operating conditions: Initial oven temperature of 60ºC (held for 0.1 min) followed by an increase in temperature at a rate of 10ºC min^{-1} to 140ºC. Temperature was then increased 40ºC min^{-1} to 200ºC and was held for 3 minutes. The temperature of the flame ionization detector temperature was 250ºC.

Volatile fatty acids in rumen fluid samples were identified by comparison to retention times of known compounds in the standard. Volatile fatty acids quantified included acetate, propionate, isobutyrate, butyrate, isovalerate and valerate. Total concentration of VFA is expressed as mM and individual VFAs are expressed as a percentage of total VFA.

4.2.6. Statistical Analysis

Trial 1

Nutrient digestibility data was analyzed as a randomized complete block design with the individual steer as the experimental unit. Analysis of variance was conducted using the MIXED procedure of the SAS Institute, Inc. (Cary, NC). The model included the fixed effect of dietary treatment and significance was declared at $P \leq 0.05$. The Kenward Roger adjustment on denominator degrees of freedom was used. Orthogonal polynomial contrasts ($P \leq 0.05$) were used to examine linear, quadratic or cubic effects of barley or LLH-HOG oat inclusion rate.

Trial 2

The experiment was conducted using a switchback repeated measures design. Rumen fermentation parameters (pH and VFA concentrations) were analyzed using the MIXED model procedure of SAS (version 9.1, SAS Institute Inc. Cary, NC) using repeated measures with the random effect of steer and the fixed effects of treatment (diet). The model included the main effects of diet (treatment), time and the time by treatment interaction. The Kenward Roger adjustment on denominator degrees of freedom was used. Least square means were calculated, and all effects were declared significant at $P < 0.05$. When F-tests were significant ($P \leq 0.05$), means were compared using the Tukey-Kramer HSD (Honestly Significant Difference) test procedure.

4.3. Results and Discussion

4.3.1. Diets

Trial 1

The chemical compositions of the LLH-HOG oat prototype, barley grain and barley silage used in this study are presented in Table 4.2. The DM and OM for both the LLH-HOG oat and barley diets increased as the proportion of grain increased in the diet (Table 4.1). Crude protein content was similar for the control and barley grain-based diets (28BG, 56BG and 84BG). However, CP content increased as the proportion of LLH-HOG oat increased in the 28OG, 56OG and 84OG diets. This increase reflected the higher CP content of the LLH-HOG oat prototype (17.0%) (Table 4.2) compared to the barley silage (12.4%) and/or barley grain

(12.8%) (Table 4.2). The EE for the LLH-HOG oat diet increased as grain inclusion increased, reflecting the higher oil content of the LLH-HOG oat (9.3%) that was selectively bred into this new variety. In comparison, the EE for the barley diet decreased as the proportion of barley grain increased, reflecting the low oil content of this cereal grain (2.1%) vs. the barley silage (3.6%). Similarly, the ADF content was higher in the LLH-HOG oat diets compared to the barley diets, reflecting the higher ADF content of the LLH-HOG oat (15.1%) relative to barley (5.1%). The neutral detergent fibre content followed a similar pattern, being higher in the LLH-HOG oat diets compared to the barley diets, again reflecting the higher NDF content of LLH-HOG oat (30.2%) relative to barley (17.6%).

Although the intent of this study was not to evaluate animal performance, all diets fed during this trial exceeded a minimum of 12.0% protein which exceeded NRC (1996) requirements for growth for the steers used in this study. As such, no additional protein supplement was fed.

Trial 2

The ingredient make-up and chemical analysis of the diets fed in Trial 2 is presented in Table 4.3. Similar to the feedlot finishing study described in the previous chapter, the EE content of the LLH-HOG oat diet exceeded that of the barley grain-based diet reflecting the breeding program targets for the LLH-HOG oat grain. Similar to diets fed during the finishing trial, ADF and NDF levels were greater in the LLH-HOG oat diet compared to the barley diet. This is consistent with diets that include a large proportion of oat grain, as the hull can constitute up to 25% of the total weight of oat grain (Crosbie et al 1984).

4.3.2. Total Tract Digestibility Study

The effect of barley and LLH-HOG oat inclusion on DMI and total tract nutrient digestibility is presented in Table 4.4.

Table 4.4. Effect of barley and LLH-HOG oat inclusion on dry matter intake and total tract digestibility of feed nutrients

	Grain Content of Diet								Contrast *P*-value[Z]					
	Silage		Oat		Barley				Oat			Barley		
Item	0	28	56	84	28	56	84	SEM	L	Q	C	L	Q	C
DMI (kg)	8.4	9.8	10.2	9.9	10.6	11.2	10.5	0.58	0.13	0.16	0.90	<0.01	<0.01	0.91
Digestibility of nutrient fractions														
DM %	61.4	62.7	58.0	60.8	65.1	65.2	74.4	1.64	0.92	0.17	0.24	<0.01	0.03	0.02
OM %	63.1	65.2	60.5	63.7	66.9	67.2	76.2	1.61	0.72	0.29	0.15	<0.01	0.04	0.03
CP %	71.1	70.5	74.7	78.2	67.9	62.7	71.1	1.26	0.14	<0.01	<0.01	0.25	0.03	0.04
EE %	65.5	81.4	87.4	88.4	69.0	67.2	71.7	1.34	<0.01	<0.01	<0.01	0.06	0.74	0.09
ADF %	49.0	44.4	24.6	17.9	46.8	38.9	52.1	5.13	0.72	<0.01	0.18	0.95	0.17	0.27
NDF %	52.1	49.0	29.8	27.1	49.3	55.1	52.1	4.48	0.73	<0.01	0.51	0.76	0.99	0.37
GE %	61.4	63.4	59.1	62.3	64.7	64.4	73.7	1.64	0.74	0.36	0.14	<0.01	0.04	0.03
DE (kcal/kg)	2728	2798	2603	2747	2918	2951	3440	73.46	0.86	0.28	0.15	<0.01	0.02	0.03

[Z]L = linear contrast; Q = quadratic contrast; C = cubic contrast.

4.3.2.1. Feed Intake

There was no effect ($P > 0.05$) of LLH-HOG oat inclusion rate on DMI (Table 4.4). This is in contrast to the barley grain-fed steers which exhibited a quadratic increase ($P < 0.01$) in DMI with increasing barley grain inclusion rate. These results contrast with the results from the feedlot performance trials described in Chapter 3 where steers fed the LLH-HOG oat exhibited a reduction in DMI as the proportion of LLH-HOG oat grain increased in the diets. The results of the current study however are consistent with Arya (2009, unpublished data) who observed no effect of increasing inclusion levels of CDC S0-1 oat on DMI in a study evaluating feeding behaviour of heifers fed high concentrate diets. Fuhr (2006, unpublished data) reported no effect on feed intake when an early prototype of the LLH-HOG oat (01-499-04) was evaluated in a digestibility study involving sheep. It is possible that the evaluation of feed intake in digestibility studies in which animals are fed individually is difficult to compare to large-scale feeding trials. In the feedlot performance studies described in the previous chapter and the subsequent study of Arya and McKinnon (2011), decreased feed intake was a consistent effect of increased inclusion levels of the LLH-HOG oat.

The quadratic increase observed for DMI in the barley-fed steers likely reflects the increased energy density of barley grain relative to the barley silage it replaced and indicates that the animals had met their net energy requirements at the higher inclusion levels, thus the plateauing in DMI. Lardy et al. (2004) reported a linear response to higher levels of barley supplementation when evaluating the effect of supplemental barley for forage-fed cattle. In their study, however, the maximum level of barley supplementation was 2.4 kg d^{-1}, which was substantially lower than the amount of barley fed at the maximum inclusion level in the current study.

4.3.2.2. Nutrient Digestibility

Cubic effects for apparent digestibility of DM (P =0.02) and OM (P =0.03) were observed as the proportion of barley grain, but not LLH-HOG oat (P=0.24 and P=0.15, respectively) increased in the diet (Table 4.4). The positive response to the barley grain likely reflects its higher non-structural carbohydrate content relative to the barley silage. When forages high in structural carbohydrates are replaced with cereal grains, diet digestibility typically

increases (Driedger and Loerch 1990). Loerch (1990) observed a 36% improvement in DM digestibility for cattle limit-fed a high concentrate diet compared to cattle fed a diet high in corn silage. In contrast, no effect was observed for DM and OM apparent digestibility of the LLH-HOG oat diet. This is surprising and inconsistent with expected results as the LLH-HOG oat also contains significant non-structural carbohydrate (starch, 50.9% of DM, Table 3.3). Ruminant animals depend on cellulolytic bacteria to digest cellulose (Russell and Wilson 1996). It is possible that that the nature of the lipid in the LLH-HOG is negatively affecting fibre digestion in the rumen. Dietary lipids can affect ruminal digestion (Chilliard 1993). Hess et al. (2007) reported a decrease in total tract OM digestibility when supplemental fat was fed to ruminants consuming high-forage diets. In a study examining the toxic effects of polyunsaturated (PUFA) and monounsaturated fatty acids, PUFA were found to be much more toxic to *Butyrivibrio fibrisolvens* than saturated fatty acids (Maia et al. 2010). *B. fibrisolvens* is important in fibre digestion in ruminants (Van Soest 1994;Russell and Rychlik 2001).

It is also possible that the steers fed the LLH-HOG oat diet were affected by acidosis as a result of differences in the rate and extent of starch degradability between oat and barley grain. As reported by Russell and Wilson (1996), a decrease in fibre dry matter digestibility occurred when purified corn starch was added to a diet containing corn cobs and alfalfa hay. Celluloytic ruminal bacteria cannot exist in a low ruminal pH environment (Russell and Wilson 1996). The ADF of the LLH-HOG oat grain (15.1% Table 4.2) is three times higher than the ADF of the barley grain (5.1%, Table 4.2). Therefore, a reduction in the cellulolytic microbial population may have a larger effect on DM and OM apparent digestibility in the oat-fed cattle compared to the barley-fed cattle. The potential effect of acidosis will be described in more detail in the discussion of the second experiment.

Apparent crude protein digestibility increased in a cubic fashion for both the LLH-HOG oat ($P < 0.01$) and barley-based ($P = 0.04$) diets as grain content increased (Table 4.4). At maximum grain inclusion levels, the CP apparent digestibility of the LLH-HOG oat diet was higher than the CP apparent digestibility in the barley diet (78.2% vs 71.1%). This was likely due to the higher CP content of the LLH-HOG oat compared to the barley grain (17.0 vs 12.8%, Table 4.3). The result also may also indicate that rumen degradability of the protein in the LLH-HOG is high and will support lean tissue accretion in growing and finishing cattle.

A cubic increase ($P < 0.01$) was observed for EE apparent digestibility for the LLH-HOG oat diet (Table 4.4). As noted in Table 4.1, the EE content of the LLH-HOG diet increased as grain content increased. This reflected the intent of the crop breeding program to increase the oil content of the groat in an effort to increase the energy value of oat grain. Apparent EE digestibility was highest (88.4%) at the maximum LLH-HOG oat inclusion level and reflects the high digestibility value for supplemental fat in diets (Jorquera and Zinn 2007). The reported apparent EE digestibility is overestimated as the feces were not acid hydrolyzed prior to ether extraction (Zinn and Jorquera 2007). Nevertheless, considering the magnitude of the response observed as well as the results of Arya and McKinnon (2011), it is evident that the increased fat content of the LLH-HOG oat is digestible to cattle and will contribute to the increased energy content of the grain.

Cattle fed increasing levels of the LLH-HOG oat exhibited quadratic decreases in apparent ADF ($P < 0.01$) and NDF ($P < 0.01$) digestibility (Table 4.4). A number of reports have indicated that the addition of dietary lipid and more specifically PUFA can disrupt rumen fermentation, causing reduced digestibility of non-lipid energy sources. Jenkins and Palmquist (1984) reported that ruminal digestion of structural carbohydrates can be reduced 50% or more by less than 10% added dietary fat. In an excellent review of dietary fat metabolism, Chilliard (1993) reported that these effects can be due to reduced protozoan and bacterial growth especially for strains that are cellulolytic in nature. These include *Ruminococcus albus*, *Ruminococcus flavefaciens* and *Fibrobacter succinongenes* (Russell and Rychlik 2001). These researchers also noted the importance of bacterial attachment for cellulose digestion. More recently, Harvatine and Allen (2006) observed that the addition of fat supplements may not increase energy intake because of decreased DMI and negative associative effects on ruminal digestion of NDF. It is possible that the unsaturated FA nature of the oil in the LLH-HOG oat (Table 3.4) has a toxic effect on cellulolytic bacteria, resulting in the disruption of rumen fermentation and the impaired fibre digestibility observed in the current study. It is also possible that the oil in the groat is coating feed particles in the rumen, preventing bacterial attachment required for cellulose digestion.

In contrast, no effect was observed for apparent ADF (P=0.17) and NDF (P=0.37) digestibility as the proportion of barley grain increased in the diet, as the low level of fat in the

barley grain (2.1%, Table 4.2) did not appear to affect rumen fermentation of the dietary fibre fractions (Table 4.4).

A cubic increase was observed for apparent GE (P =0.03) and DE (P =0.03) digestibility for the barley grain-based diets, with the largest effect (73.7%) observed at the maximum inclusion level (84BG) (Table 4.4). The increase in apparent GE and DE digestibility is not surprising as the inclusion of cereal grains increases the energetic density of the diet, as rapidly fermentable non-structural carbohydrates such as starch replace the structural carbohydrates in forage (Huntington 1997).

However, no effect was observed for apparent GE (P >0.05) and DE (P >0.05) digestibility for the LLH-HOG oat diet (Table 4.4). This in effect indicates that dietary energy content did not increase as the LLH-HOG oat replaced the barley silage of the control diet. This is surprising as the LLH-HOG oat contains a significant proportion of non-structural carbohydrate in the form of starch and the increase in groat-oil content relative to barley should have resulted in some improvement in apparent GE and DE digestibility. The apparent GE digestibility for the 84OG diet was determined to be 62.3% (Table 4.4). This is similar to the result reported by Devlin et al. (1977) who determined the apparent GE digestibility of a calf starter ration containing 90.2% of a high fat oat cultivar (9-10% lipid content) to be 62.3%. In this same study, the apparent GE digestibility for the regular oat diet was determined to be 62.5%. The selective breeding for a high oil groat in the new oat has greatly increased the lipid content of this grain in relation to other cereal grains such as barley.

The hull of the LLH-HOG oat is comprised of structural carbohydrates and represents approximately 25% of the content of the oat. At all inclusion levels of the LLH-HOG oat in the digestibility study diets, ADF and NDF content were higher, reflecting the contribution of the hull in the LLH-HOG oat diets relative to the barley diets (Table 4.1). Oat hull is characterized by its high fibre content and low digestibility (Thompson et al. 2001). Although the crop breeding program was successful in reducing the ADL content of the LLH-HOG oat to 1.0% DM compared to 4.0 to 5.5% ADL in the DM of a typical oat, there may be other compounds in oat hulls that can lead to reduced fibre digestion. Garleb et al. (1991) identified that phenolic monomers may play an active role in the inhibition of fibre degradation in the rumen. It has been suggested that the formation of ester linkages between the phenolic monomers and hemicellulose may be responsible for inhibiting fibre digestion (Titgemeyer et al. 1991). A reduction in fibre

digestion in the LLH-HOG oat diets may help explain the lack of an effect on GE digestibility observed in this trial.

4.3.3. Rumen Fermentation Studies

4.3.3.1. Rumen pH

Rumen pH measurements are presented in Table 4.5. Mean rumen pH was lower (P=0.01) for steers fed the LLH-HOG oat-finishing diet compared to steers fed the barley-finishing diet (5.9 ± 0.52 vs. 6.3 ± 0.40). Finishing diets contain a large proportion of cereal grain (70% to 90% of the diet DM) with starch the major energy-yielding component (Huntington, 1997). As reported by Owens et al. (1997), rapid fermentation of starch in the rumen increases acidity and can result in digestive disorders such as acidosis leading to feed intake problems.The rate and extent of starch degradation in the rumen varies with grain source and the difference in rumen pH observed in this study may be due to differences in the physicochemical properties of the LLH-HOG oat and barley grain. The feedlot finishing trial described in Chapter 3 reported that the starch content of the LLH-HOG oat was 50.9% (DM basis) (Table 3.3). This was lower than estimates of 60% starch of the dry matter of oat grain reported by Hoover et al. (2002).

Table 4.5. Effects of grain source (LLH-HOG oat or barley) in finishing diets on rumen fluid parameters

	Treatment			*P-value*[z]		
Item	Oat	Barley	SEM	D	T	D×T
pH	5.9	6.3	0.07	0.01	<0.01	<0.01
Total VFA (mM)	88.7	93.6	7.00	0.64	<0.01	0.01
Acetate %	46.9	49.0	2.30	0.56	<0.01	0.01
Propionate %	32.1	33.2	5.70	0.90	<0.01	0.36
Acetate:propionate	1.7	1.7	0.30	0.91	0.28	1.00
Butyrate %	5.7	7.6	1.00	0.22	0.08	1.00
Isobutyrate %	0.5	0.8	0.10	0.12	<0.01	0.64
Valerate %	0.8	1.1	0.13	0.15	0.02	0.26
Isovalerate%	1.7	1.6	0.37	0.85	<0.01	0.64

[z] P values for the effect of diet (D), time (T) and diet × time interaction (D×T).
[a,b] Means with different superscripts are significantly different at $P \leq 0.05$.

These workers examined the physicochemical properties of oat starch in cultivars of oat grain grown in Canada. The increase in the lipid fraction of the new LLH-HOG oat may have resulted in a reduction in the starch content of the endosperm of this new oat variety. Less starch in the LLH-HOG oat diet should have reduced the amount of fermentable carbohydrates in the rumen and it would be reasonable to assume that rumen pH in steers fed the oat finishing diet would be higher than the rumen pH of the steers fed the barley diet. However, while the starch content of oat grain is typically lower than that of other feed grains such as barley and corn, the rate and extent of starch degradation is higher (Herrara-Saldena et al. 1990). These researchers observed starch degradation in oat grain at 15.1% h^{-1} compared to barley at 8.8% h^{-1}, and that 28.0% of the total starch in oat grain was degraded following a 60-minute *in vitro* incubation compared to 18.1% for barley. Yu and Niu (2009) observed that the DM, starch and protein degradation rates of the successor to the LLH-HOG cultivar (CDC S0-1) were similar to other oat varieties (CDC Dancer and Derby) so it is plausible that an increase in the rate and extent of starch degradation resulted in the lower mean pH observed in the current study. Results from the current study and Yu and Niu (2009) indicate that the physicochemical characteristics of LLH-HOG oat are similar to other oat cultivars and the rate and extent of starch degradation is rapid and extensive. Detailed *in situ* ruminal studies comparing the LLH-HOG oat to other cereal grains are required to confirm these differences.

Figure 4.1 illustrates the diurnal variation in rumen pH for the diets fed during this study. As expected , rumen pH in cattle fed either declined following the morning feeding and then slowly recovered throughout the day prior to the afternoon feeding. Following the afternoon feeding, rumen pH declined to a greater extent than observed following the morning feeding. This dinural change in rumen pH is a result of rumen bacterial fermentation activity and has been well documented (Nagara and Lechtenberg, 2007).

A significant diet and time effect ($P<0.01$) was observed in this study. The extent of pH decline in oat- fed cattle was greater ($P<0.001$) than barley-fed cattle. Ruminal acidosis may occur following ingestion of excessive amounts of readily fermentable carbohydrate (Owens et al. 1998). The mean rumen pH (5.9) observed for cattle fed the LLH-HOG finishing diet was above the threshold of 5.6 commonly used to define SARA and did not decline to a level that would indicate steers were in acute acidosis which occurs when ruminal pH is lower than 5.1 for a period of time (Nocek 1997). Sub-acute ruminal acidosis can occur when the pH of the rumen

is below 5.6 for more than three hours (Krehbiel et al. 1995; Gozho et al. 2005). As illustrated in Figure 4.1, the decline in rumen pH in the postprandial periods observed in the oat-fed steers indicates that these animals may have been affected by SARA for certain periods of the day and could further explain the reduction in feed intake observed in the feedlot finishing performance study described in Chapter 3.

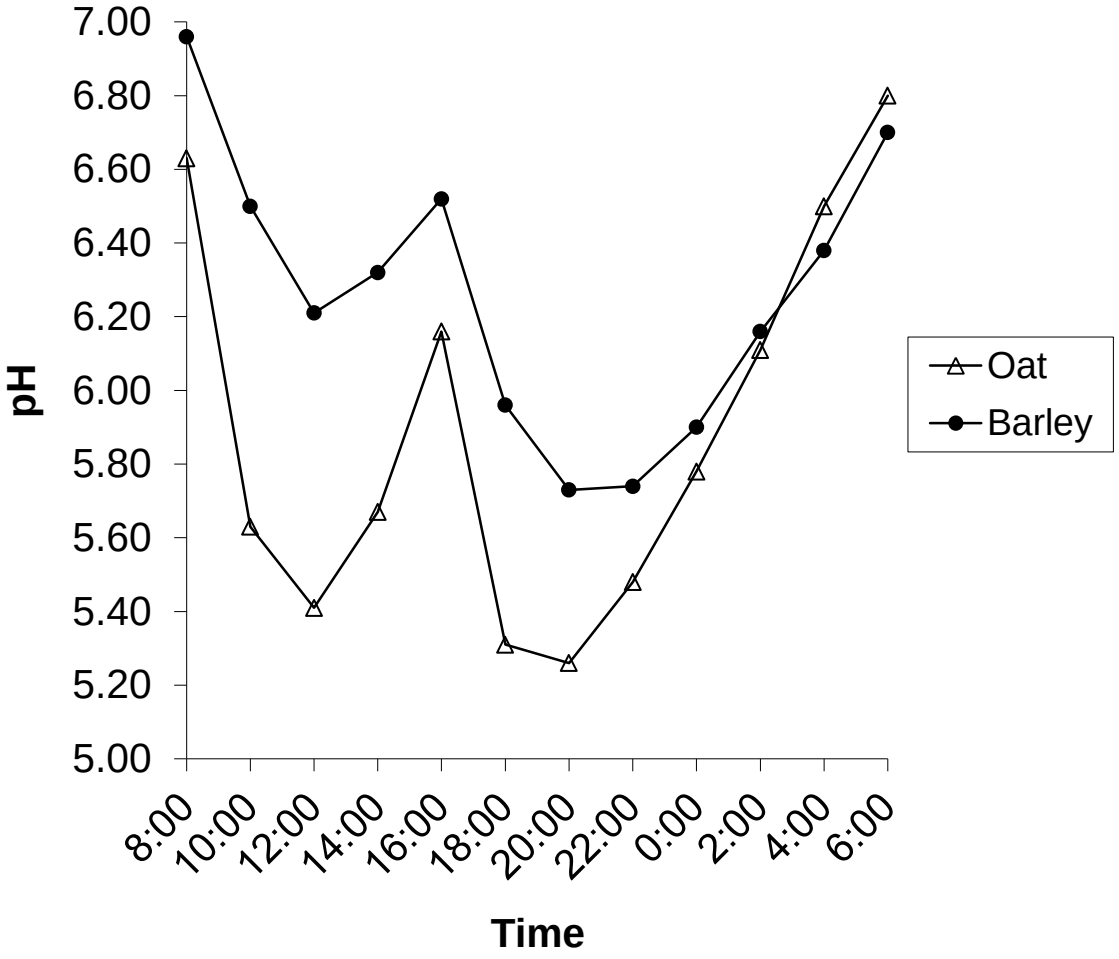

Figure 4.1. Interaction (*P*<0.01) between diet and time on rumen pH measurement

It has been observed that both SARA and acute acidosis can lead to variation in and reduced DMI, leading to lower animal performance (Owens et al. 1998). However, given the extent of the

DMI reduction observed in Chapter 3, it is unlikely that SARA is the sole factor responsible for the reduction in DMI observed in the previous study.

4.3.3.2. Ruminal VFA

No significant diet effect was observed for total ruminal VFA concentration but as illustrated in Figure 4.2, a time and diet interaction (*P*=0.01) was observed.

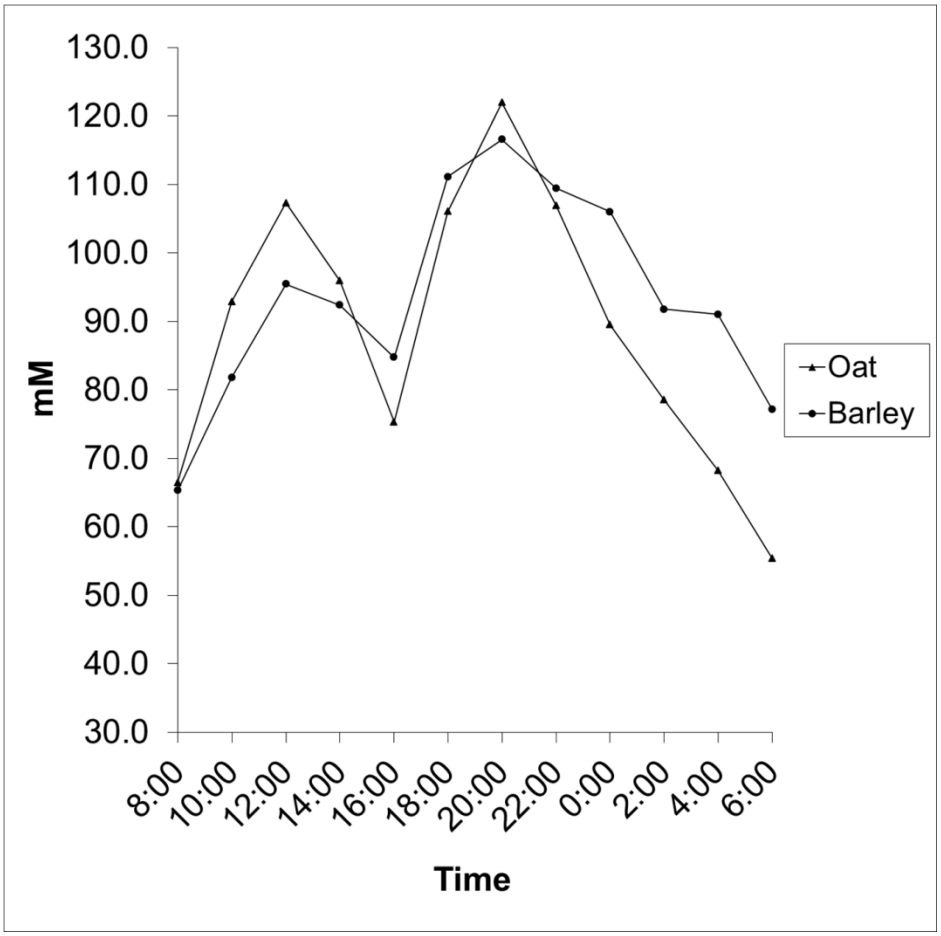

Figure 4.2. Interaction (*P*=0.01) between diet and time on VFA production

Maximum VFA production in oat-fed cattle exceeded maximum VFA production in barley fed cattle. However, the rate and extent of decline for VFA was greater in the oat-fed steers relative to the barley-fed steers. This would indicate that rate of fermentation of the LLH-

HOG oat diet was more rapid than the barley-diet and may have been responsible for the more rapid decline in rumen pH observed in the oat-fed cattle in this study.

No significant diet effect was observed for acetate concentration was observed but as illustrated in Figure 4.3, a time and diet interaction (*P*=0.01) was observed. The peak concentration of acetate was higher in oat-fed cattle compared to barley-fed cattle in both post-prandial periods. The rate and extent of decline in acetate concentration was also greater in the oat-fed cattle compared to the barley fed cattle.

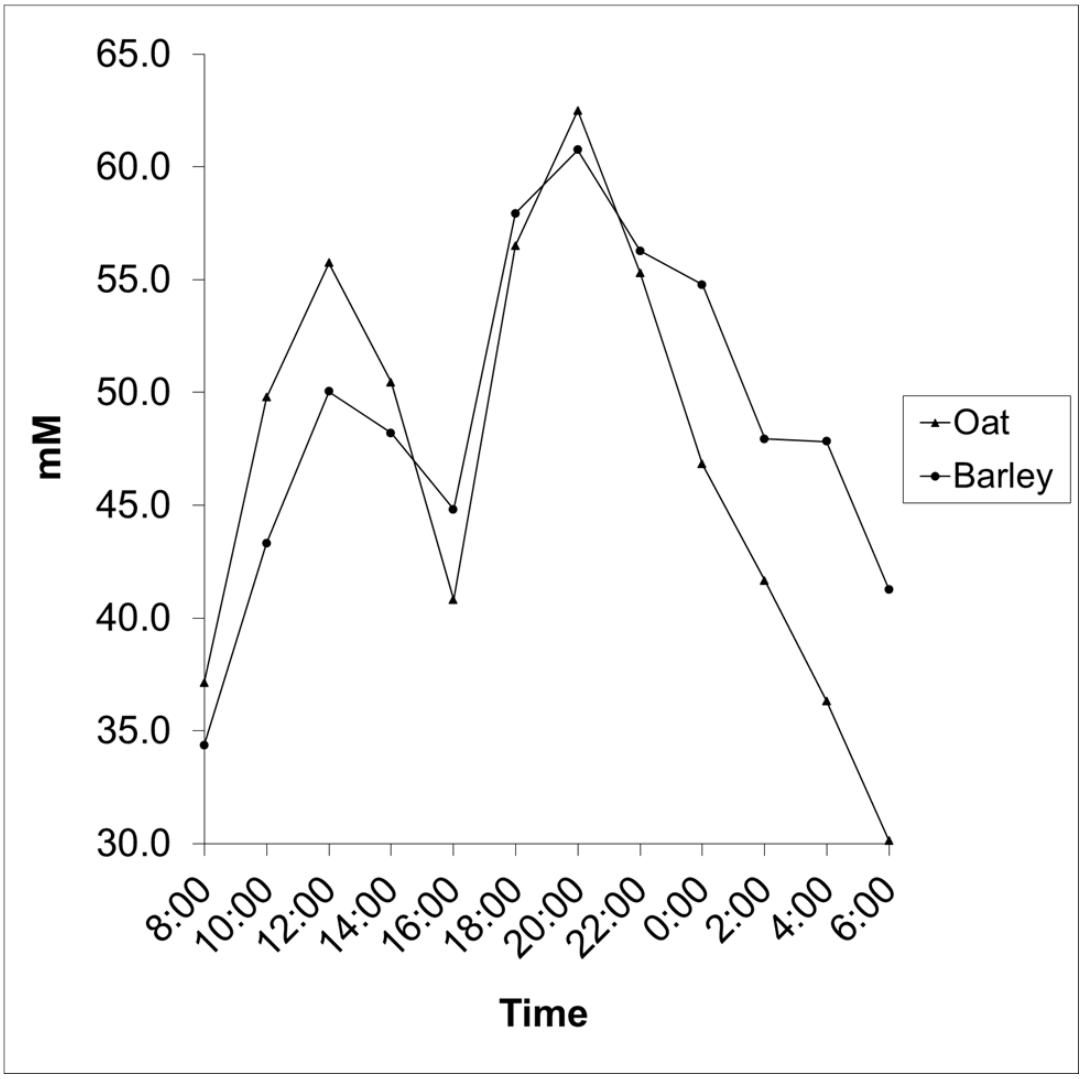

Figure 4.3. Interaction (*P*=0.01) between diet and time on acetate production

No significant effects were observed to molar proportions of the other individual VFA measured in this study (propionate, butyrate, isobutyrate, valerate or isovalerate) in the steers fed

the LLH-HOG oat or barley finishing diets. This would indicate that the LLH-HOG oat and barley have similar rumen fermentation characteristics with respect to VFA production. This is consistent with results observed in the subsequent research project completed by Arya (2009) in cattle fed a similar barley-based finishing diet and a finishing diet containing the CDC-SO1 oat.

4.4. Conclusion

The results of this study indicate that the digestible energy value of the LLH-HOG oat is not equivalent to that of barley grain. The negative effects observed in apparent fibre (ADF and NDF) digestibility are likely a result of the polyunsaturated fatty acid profile of the LLH-HOG oat and its toxic effect on cellulolytic bacterial fermentation. The apparent EE and CP digestibility coefficients indicate that the oil and protein fractions of the LLH-HOG oat were highly digestible, which should support lean muscle accretion and weight gain in growing cattle.

The lower mean rumen pH observed in the metabolism study for cattle fed the LLH-HOG oat finishing diet compared to cattle fed the barley finishing diet indicates that the starch in the LLH-HOG oat is rapidly degraded and that the high oil content in the new oat does not reduce the risk of ruminal acidosis in finishing cattle.

5.0 GENERAL DISCUSSION AND CONCLUSIONS

Oat remains a popular option for cereal growers in many regions of western Canada as a high-yielding source of grain, but from an economic perspective, is predominantly grown to supply the human food market where demand for oat products continues to increase. In the feed market, oat grain has always been a popular cereal grain for horse owners and there is a significant market for oat grain with a heavy test weight that has been cleaned and bagged. In terms of mainstream feed grain markets, beef cattle producers are always looking for the development of new feed grains that can compete with existing grain varieties in terms of agronomics and animal performance. A new oat grain will have to be competitive on a cost per unit of energy basis and animal performance must not be compromised if market share is to be increased.

Traditionally, oat has been perceived as a feed grain useful for starting cattle on feed or in creep feeds for nursing calves. Oat has a higher proportion of hull relative to other feed grains, resulting in an increased fibre and lower energy content. This is contrary to the demands of beef feedlot production where feed efficiency and cost per unit of gain is typically improved with increasing dietary energy levels (Gibb et al. 2009).

In an effort to overcome the energy deficiencies of current oat cultivars, the Crop Development Centre at the University of Saskatchewan was successful in breeding an oat combining the properties of a low ADL hull with a high oil groat. The LLH-HOG oat used in these studies had improved hull digestibility due to a less lignified hull (1% ADL in the grain DM) and an oil content that exceeded 8.5% of the grain DM. This increase in lipid content was considerably higher than that of oat cultivars grown in Canada that typically have an oil content of 4.0-5.5% of the grain DM. The intent of the selective breeding program was to develop an oat with increased digestible energy content to incorporate into feedlot cattle diets and match animal performance compared to barley-based feedlot diets. It was anticipated that an increase in the lipid content of the LLH-HOG oat would offset its lower starch content and the higher proportion of hull compared to barley grain. The addition of fat to finishing cattle diets has been shown to improve ADG and feed efficiency by increasing the energy density of the diet (Zinn 1989a).

In the first backgrounding feeding study (Trial 1), animal performance was similar between the oat- and barley-fed cattle. Lower feed intake was observed in cattle fed the LLH-HOG oat-based diet but similar ADG was observed compared to cattle fed the barley-based diet. As a result, an improvement in feed efficiency was observed. The EE of the LLH-HOG oat diet was determined to be 5.9% (DM basis). Doreau and Chilliard (1997) reported that the addition of up to 5% fat to ruminant diets has minimal effects on feed intake and diet digestibility. Although the threshold established by these workers was exceeded, it did not exceed the maximum threshold of 7% of diet DM identified by Zinn and Jorquera (2007) who reported that supplemental dietary fat needs to exceed 7% in ruminant diets to negatively affect rumen fermentation and feed intake.

Similar results were observed in the backgrounding phase of the second performance study (Trial 2). Cattle fed the LLH-HOG oat diet for the initial 56 days of the study had lower feed intake compared to barley- or corn-fed cattle and lower ADG was also observed. However, it is important to note that the improvement in feed efficiency observed in Trial 1 was also observed during the initial feeding period in Trial 2. These results with backgrounding cattle support the observations of Zinn and Jorquera (2007) who stated that the addition of supplemental fat to animal diets can improve feed efficiency. The EE content of the LLH-HOG oat diet fed in the backgrounding phase of Trial 2 was 6.5% (DM basis). The additional lipid content of the LLH-HOG oat diet may have contributed to the decrease in feed intake and the reduction in animal performance observed. However, from a practical perspective for backgrounding cattle in feedlots where maximum gain is not the desired outcome, the improvement in feed efficiency should not be overlooked as an important consideration when selecting a cereal grain for these diets.

The finishing phase of Trial 2 clearly indicated that increasing the proportion of LLH-HOG oat in finishing diets negatively affected DMI and resulted in lower ADG, poorer feed efficiency, increased days on feed, lighter carcass weight, lower dressing %, and smaller *l. dorsi* area. There are two possible explanations for the reduction in feed intake observed during the finishing period of Trial 2. First, the LLH-HOG oat finishing diet contained 8.0% EE (DM basis) which exceeded the recommended total lipid content in finishing diets of 7.0% of dietary dry matter (Zinn and Jorquera 2007). These workers identified that optimal feeding value of supplemental fat is obtained when total lipid intake in finishing diets does not exceed 1.0 g kg^{-1}

BW or 7% of the dietary DM in feedlot finishing diets. Based on a final BW of 623.3 kg and DMI of 9.56 kg during the finishing period, the steers fed the LLH-HOG oat diet had a lipid intake of 1.2 g kg^{-1} BW. These researchers noted that a reduction in intestinal fatty acid digestibility may result from limited bile production capacity and that total fatty acid intake per unit of body weight is an important consideration when formulating diets containing supplemental fat. Secondly, it is possible that differences in the physicochemical characteristics in the feed grains may have resulted in differences in ruminal starch degradation rates and that the lower feed intake observed in LLH-HOG oat fed cattle may have been a result of SARA. The lower pH observed in the LLH-HOG oat fed cattle in the metabolism study indicated that these steers may have been affected by SARA for periods of time during the day and may have been a factor in the reduction in DMI observed in the feedlot finishing performance studies.

The new high energy oat has significant potential to replace barley grain in feedlot backgrounding diets. Based on the results in Trials 1 and 2 of the animal performance studies, the inclusion of LLH-HOG oat grain should be limited to no more than 50% of the diet DM in backgrounding studies to minimize the negative effects of higher inclusion levels on feed intake. The results from the studies described in this thesis support the recommendations of Zinn and Jorquera (2007) that supplemental fat should be limited to no more than 7% of diet DM.

Until the factors that limit DMI in cattle fed diets containing a high proportion of LLH-HOG oat are identified, it is recommended that the LLH-HOG oat should not be used exclusively as a grain source in feedlot finishing diets.

Further research is warranted to identify the factors that lead to a significant decrease in DMI in cattle fed the LLH-HOG oat relative to other cereal grains. Additional rumen fermentation studies are recommended to confirm the preliminary findings in this study that SARA may be a contributing factor to the lower DMI observed in cattle fed the LLH-HOG oat.

Further research may also assist in better understanding the relationship between fat intake, fatty acid composition of the LLH-HOG oat, and the effect lipid supplementation has on rumen fermentation of fibre in high concentrate diets containing this cereal grain. From a broader perspective, the identification of factors that may limit the production of bile thereby reducing the capacity of the intestine to digest fatty acids may be useful in overcoming this potential obstacle that appears to limit the use of high (>7% DM) amounts of supplemental fats and oils in feedlot finishing diets.

Additional research will be required to identify the maximum inclusion rate of the LLH-HOG oat in feedlot finishing diets before we recommend the use of this cereal grain for this purpose. While the breeding program successfully increased the oil content in the groat and reduced the lignin content in the hull, there are additional factors that need to be overcome before the widespread substitution of this cereal grain with barley is recommended in feedlot finishing diets.

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